This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

V M
600
C4

UC-NRLF
$B 76 897

NOTES
ON
STEAM ENGINEERING

ARRANGED FOR THE USE OF OFFICERS OF THE
OLD LINE OF THE NAVY

BY
SEVERAL OFFICERS OF THE NAVY

PUBLISHED BY THE
U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.
1901

SIGILLVM · UNIVERSITATIS · CALIFORNIENSIS
FIAT LVX
MDCCCLXVIII
EX LIBRIS

Chandler, L. H.

NOTES

ON

STEAM ENGINEERING

ARRANGED FOR THE USE OF OFFICERS OF THE
OLD LINE OF THE NAVY

BY
SEVERAL OFFICERS OF THE NAVY

PUBLISHED BY THE
U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.
1901

VIII 60
C 4

Copyright, 1901, by L. S. VAN DUZER.

The Lord Baltimore Press
THE FRIEDENWALD COMPANY
BALTIMORE, MD., U. S. A.

NOTE.

Since the printing of this book, I have learned that the original notes, of which this book is practically a copy, were collated and written up in 1892 by Passed Assistant Engineers George H. Kearny and R. R. Leitch, U. S. Navy.

L. H. C.

360513

PREFACE

At the request of a number of friends I have undertaken to put into form for the printer this set of notes, which has gradually grown into the shape in which I received them through the efforts of the officers of the old engineer corps, by whom they were used in preparing themselves for examination for promotion to the grade of chief engineer.

My special aim has been to prepare something that will be of value to the officers of the old line, who not only may be hereafter called upon to perform duties with which they now have little familiarity, but who will certainly be required to pass examinations in steam engineering. Having this end in view, I have felt that I could better appreciate the obscure points in the text before me than could some person more familiar with the subject. In other words, possessing little knowledge of the subject myself, I have felt that I could find the points that would prove difficult to others in a similar situation better than one of the old engineer officers could. This, therefore, is my apology for attempting the work.

I have contributed nothing to the text except the work of arrangement and revision, and throughout have received every assistance from the officers of the Bureau of Steam Engineering, by whom my work has been carefully revised.

I trust that steam engineering experts will look with sympathy on this work and forgive its many faults. It is not intended for their use. I also hope that my labors may prove of some service to the many officers who are in the same situation that I am.

No attempt has been made to make this a complete work on steam engineering, the effort being merely to preserve and simplify the standard answers to these old examination questions.

I have been assisted in this work by Lieutenants R. S. Griffin and Cleland Davis, who have revised and corrected the text.

L. H. Chandler.

March, 1901.

QUESTIONS PRESCRIBED BY U. S. NAVY REGULATION CIRCULAR NUMBER 109, OF JULY 25, 1892, FOR USE IN EXAMINATION OF OFFICERS FOR PROMOTION TO GRADE OF CHIEF ENGINEER, WITH ANSWERS THERETO.

(Compiled and Revised by a Number of Officers of the Navy.)

While the regulation circular above referred to is no longer in force, these questions cover practically the whole subject, and they have been reproduced, with their answers, on account of their general value, especially to officers of the old line who have to qualify as engineers.

Under the above-mentioned circular, the examining board could ask the candidate for promotion the designated number of questions under each subject enumerated below, the selection of the individual questions resting with the board:

Under Subject No. 1; one question.

Under Subject No. 2; two questions.

Under Subject No. 3; two questions.

Under Subject No. 4; one question.

Under Subject No. 5; three questions, one on each subject, the use of works of reference being permitted in solving problems.

Under Subject No. 6; one question.

INDEX OF SUBJECTS AND QUESTIONS

PAGE

Subject No. 1.—Design of Marine Machinery.................... 11

Question No. 1.—Calculate the horse-power necessary to secure a given speed in a certain vessel.................... 11

Question No. 2.—Calculate the dimensions of cylinders for a given horse-power 19

Question No. 3.—Calculate the dimensions of condensers and pumps for engines of given dimensions.................... 22

Question No. 4.—Calculate dimensions of a set of boilers to furnish steam for a given horse-power.................... 25

Question No. 5.—Calculate the dimensions of propellers to drive a vessel at a given speed.................... 27

Subject No. 2.—Duties as Chief Engineer of a ship in Commission. 30

Question No. 1.—What procedure should be adopted on joining a ship to ascertain that the machinery is in proper condition; that is, what parts should be inspected, and how can the needed information be best secured in the shortest time? 30

Question No. 2.—How should the men of the engineer's force be stationed for steaming watches and for general and fire quarters? (The examining board gives the number of the engines and auxiliaries, and of the boilers, with an idea of the general arrangements as regards subdivision. With this data given, the candidate must state the number of men required and their assignment.).................... 31

Question No. 3.—Give a statement of points to be observed in caring for machinery and the precautions to be observed (*a*) when in use; (*b*) and when not in use, in order to insure its readiness for service.................... 33

Question No. 4.—Explain how best to obtain economy in the use of coal, oil, etc. (This will involve such considerations as the number of boilers to be used for a given power, the rate of combustion of coal, the steam pressure and point of cut-off to be used, the economical speed of the ship, and the best method of lubrication.).................... 34

Question No. 5.—Give a list of parts of steam machinery subject to wear, and state the course to pursue to maintain efficiency, together with a statement of cases where deterioration is certain and cannot be compensated.................... 35

Question No. 6.—Give a list of the machine and hand tools that are carried on board a modern war vessel, with a state-

PAGE

ment of new and repair work that can be performed aboard. (Both the list of tools and of work should be given in a general way, not going much into detail, the object being to see that the candidate knows what work can be done on board and what must be done at a shop on shore.) 36

Question No. 7.—Give a list of the more important stores and spare parts usually carried on board modern war vessels 37

Question No. 8.—What inspection and tests should be used in selecting coal, oil; and rubber? 38

Subject No. 3.—Duties of an Engineer on Shore at a Navy Yard or as an Inspector of Machinery Building by Contract...... 43

Question No. 1.—Describe a general survey of the machinery of a ship returned for refitting at the end of a cruise, and state what parts would require most careful examination and what work would generally be done to put the machinery in thoroughly good condition....................... 43

Question No. 2.—State how estimates of time and cost are made in case of repair work. (The board will give a statement of the character and amount of repairs required.)..... 44

Question No. 3.—Name the tools and appliances generally fitted in a modern plant for the building and repair of marine machinery of large size, giving some idea of the size of the various tools, cranes, etc. 45

Question No. 4.—State the amount of work that can reasonably be expected during a working day of eight hours on any one of the following kinds of work:—(*a*) turning plain shafting; (*b*) boring large engine cylinder; (*c*) plain work in an hydraulic flanging machine (thickness of plate to be given); (*d*) riveting in an hydraulic riveter (thickness of plates and diameter of rivets to be given); (*e*) drilling rivet holes in boiler shells (thickness of plates, diameter of holes, and kind of drilling machine to be given); (*f*) planing valve seats on large cylinders; (*g*) drilling and tapping holes in condenser-tube sheets 46

Question No. 5.—Give a general idea of the method of conducting the evaporative test of a steam boiler, stating the special precautions necessary to ensure accurate results..... 49

Question No. 6.—State the preparations that would be made for a full power trial of the machinery of a modern war vessel, including a list of stores and instruments that should be furnished 54

Question No. 7.—Give a general idea of the work to be done in "laying up" the machinery of a vessel that is to be put in the ordinary 55

PAGE

Question No. 8.—Being assigned to duty as inspector of machinery, tell what special points should be looked after in the inspection of any two of the following:—.............. 56

(*a*) Cylinders;
(*b*) Condensers;
(*c*) Boilers;
(*d*) Shafting;
(*e*) Piston and connecting rods and valve stems;
(*f*) Pistons and valves;
(*g*) Bed plates;
(*h*) Propellers;
(*i*) Boiler and condenser tubes;
(*j*) Brass castings generally.
(*k*) In addition to the two questions under this head, the candidate will be furnished with a blue print of some part of the machinery of a naval vessel and required to write such a specification of the same as would be drawn to accompany the contract.

Subject No. 4.—Practical Work.................................. 60

Question No. 1.—Describe the method of moulding any large piece of machinery in loam, such as a cylinder, propeller, condenser, etc., from a pattern.............................. 60

Question No. 2.—Describe the method of making a pattern for a cylinder or other complicated piece of machinery..... 76

Question No. 3.—Describe the method of making a propeller pattern 89

Question No. 4.—Describe the method of moulding a propeller by sweeping up.................................. 90

Question No. 5.—Describe the machine work necessary to put a cylinder casting, as received from foundry, in condition for going in ship.................................. 92

Question No. 6.—Describe the machine work on a built-up propeller 95

Question No. 7.—Describe the machine work on a crank shaft, connecting rod, or piston rod......................... 96

Question No. 8.—Describe the manufacture of any large forging of steel or iron.................................. 99

Question No. 9.—Describe the work of building a large boiler 101

Question No. 10.—Describe the work of running lines in a ship and erecting her engines in place...................... 105

Question No. 11.—Describe the work of boring out and fitting stern tubes and shaft struts.......................... 109

Question No. 12.—Describe the details of building a condenser 111

Question No. 13.—Give an outline of the method of fitting and erecting steam and exhaust piping, with a statement of the precautions that should be observed....................... 114

PAGE

Subject No. 5.—Strength of Materials, Metallurgy and Shipbuilding 115

Question No. 1.—Work out the thickness of shell, detail of riveting, thickness of furnaces, diameter of braces in steam spaces and size and spacing of stays for a cylindrical boiler of given diameter and steam pressure........ 115

Question No. 2.—Design a crank shaft for engines of a given size, from data furnished........ 118

Question No. 3.—Design a piston rod and a connecting rod for a given engine........ 120

Question No. 4.—Work out the principal dimensions for the cylinders of a given engine, including steam ports........ 121

Question No. 5.—Give a brief outline of the process of making cast iron, explaining how the different qualities are produced 122

Question No. 6.—Give a brief outline of the common method of making wrought iron bars or plates........ 123

Question No. 7.—Describe briefly the principal methods of making steel used in machinery and structural work........ 123

Question No. 8.—Explain in a general way the manufacture of various kinds of brasses or bronzes, explaining how the proportions of the ingredients affect the principal qualities, such as strength, hardness, brittleness, etc........ 124

Question No. 9.—Explain in a general way the manufacture of the so-called "white metals" or "anti-friction" metals, the way in which they are used, and the reasons for their use. 125

Question No. 10.—Explain the methods of framing used in war vessels constructed of steel, particularly in the space to be occupied by machinery........ 125

Question No. 11.—Explain method of water-tight subdivision used on board war vessels........ 126

Question No. 12.—Explain the framing and working of plates at the stern post and where the shaft tubes are attached.... 127

Question No. 13.—Explain the drainage system and its connection to the engine-room pumps........ 127

Question No. 14.—Explain the precautions to be taken in attaching valves to the hull to maintain the strength and prevent corrosion 128

Question No. 15.—Explain the fitting of decks and framing of hatches near the machinery compartments........ 129

Question No. 16.—Explain briefly, center of gravity, center of buoyancy and metacenter. Discuss briefly the considerations that affect stability and stiffness........ 129

Subject No. 6.—Economics of Machinery........ 130

Question No. 1.—Explain briefly the advantages and disadvantages of high steam pressures and multiple expansion engines both for marine machinery in general and for war vessels 130

PAGE

Question No. 2.—Discuss briefly the advantages and disadvantages of the various styles of valve gear and valves in general use, and of those which are used in special cases where saving of weight and space is important.............. 131

Question No. 3.—Discuss briefly the considerations that govern the choice of a particular style of boiler, noting the relative merits of shell and coil boilers.......................... 131

Question No. 4.—Discuss the methods of propulsion in common use, giving important features to be secured in an efficient propeller, and explaining why the form of propeller now in use is most desirable; or what other form, if any, you think would be preferable.............................. 132

Question No. 5.—Discuss the question of the methods ordinarily employed in securing great power in marine machinery on light weight; showing what is necessary, how far it is safe to go, and what precautions in inspection must be observed in order to secure perfection in material and workmanship 132

APPENDICES.

Appendix A.—The Logical Arrangement of the Motive Power of Warships. A paper by Rear-Admiral Geo. W. Melville, U. S. N., Chief of the Bureau of Steam Engineering........... 135

Appendix B.—List of text-books of steam engineering in which elaborations of the replies contained in this book can most readily be found...................................... 154

ERRATA.

Page 45, line 21.	Should be 110 inches instead of 11 inches.
Page 47, line 30.	Should be 1/32″ cut, 3/8″ feed, instead of 1/32″ feed, 3/8″ cut.
Page 94, line 19.	Should be . . . and filed to size instead of fitted to size.
Page 96.	In rearranging the notes for publication, the paragraph about balancing of screws was re-worded and says, "This supporting mandrel must of course be of uniform diameter throughout its length." This is wrong; the two ends must be of equal diameter, but the mandrel must fit the taper hole in the hub, otherwise no results could be obtained.
Page 98, line 26.	Should be 1/100″ instead of 1/1000″.
Page 112, line 34.	Should read: and that afterwards a reamer fitting both parts is put in and all reaming . . .
Page 113, line 15.	2 inches should read 2 feet.
Page 117, line 5.	Board of Trade Rules (Seaton) should refer to "Thickness of Furnace" on next line.
Page 125, line 18.	Should be: "easily renewed and fitted. When hot they do not cut the . . .

NOTES ON STEAM ENGINEERING

ARRANGED FOR THE USE OF

OFFICERS OF THE OLD LINE OF THE NAVY

Subject No. 1.—Design of Marine Machinery.

Question No. 1.—Calculate the horse-power necessary to secure a given speed in a certain vessel.

In working out formulae the Cincinnati is taken as an example.

Various formulae are used for this purpose, the constants in them being deduced from the trials of similar vessels. In most of these formulae the I. H. P. is supposed to vary as S^3, but in practice it is found that above 17 knots it really varies as $S^{3\frac{1}{2}}$ or S^4.

A.—ADMIRALTY RULE.

Let D = displacement of vessel in tons of 2240 pounds, S = speed of vessel in knots per hour, and C = a constant varying from 175 to 300, according to size and lines of the ship and the speed. Then we may use the formula,

$$\text{I. H. P.} = \frac{D^{\frac{2}{3}} \times S^3}{C}, \text{ which gives for the Cincinnati,}$$

$$\text{I. H. P.} = \frac{(3183)^{\frac{2}{3}} \times (20)^3}{180} = 9617.$$

B.—BOULTON'S AND WATT'S RULE.

Let A = area of immersed midship section in square feet, S = speed of ship in knots per hour, and K = a constant, varying from 400 to 700, according to size, lines and speed of the ship, the value of which is determined from actual performance of vessels of similar proportions. Then we may use the formula,

$$\text{I. H. P.} = \frac{A \times S^3}{K}, \text{ which gives for the Cincinnati,}$$

$$\text{I. H. P.} = \frac{665 \times (20)^3}{550} = 9673.$$

The following table gives values for the constants used in the two formulae just given:

General Description of Ship.	Speed.	C	K
Over 400 feet long, finely shaped	15 to 17	240	620
Over 300 feet long, finely shaped	15 to 17	190	500
Over 300 feet long, finely shaped	13 to 15	240	650
Over 300 feet long, finely shaped	11 to 13	260	700
Over 300 feet long, fairly shaped	11 to 13	240	650
Over 300 feet long, fairly shaped	9 to 11	260	700
Over 250 feet long, finely shaped	13 to 15	200	580
Over 250 feet long, finely shaped	11 to 13	240	660
Over 250 feet long, finely shaped	9 to 11	260	700
Over 250 feet long, fairly shaped	11 to 13	220	620
Over 250 feet long, fairly shaped	9 to 11	250	680
Over 200 feet long, finely shaped	11 to 12	220	600
Over 200 feet long, finely shaped	9 to 11	240	640
Over 200 feet long, fairly shaped	9 to 11	220	620
Under 200 feet long, finely shaped	11 to 12	200	550
Under 200 feet long, finely shaped	10 to 11	210	580
Under 200 feet long, finely shaped	9 to 10	230	620
Under 200 feet long, fairly shaped	9 to 10	200	600
Torpedo boat, 135 feet long	20	156	
Torpedo gunboat, 230 feet long	20	186	
Third-class cruiser (Medusa), 265 feet long.	20	159	
Second-class cruiser (Terpsichore), 300 feet long	20	198	
First-class cruiser (Edgar), 360 feet long	20	276	
First-class cruiser (Blenheim), 375 feet long.	20	278	
Passenger steamer, 525 feet long	20	281	

C.—RANKINE'S RULE.

Rankine suggested a method of calculating the resistance of a ship, which is based on the resistance of the wetted surface, and which also took into account the fineness of the water lines. This method is very rarely used at present, as it cannot be employed until after the lines of the ship are known. Froude's Law is the method generally employed.

Rankine's rule is:

Rule 1.—Given the intended speed of the ship in knots; to find the least length of the after body necessary, in order that the resistance may not increase faster than the square of the speed: take three-eighths of the square of the speed in knots for the length in feet. To fulfil the same condition, the fore body should not be shorter than the after body as given by the preceding rule, and may with advantage be one and one-half times as long. The length of after body may be expressed under this rule as follows:

$z = \frac{3S^2}{8}$, where z = length of after body and S = speed in knots.

From this directly follows:

Rule 2.—To find the greatest speed in knots suited to a given length of after body in feet, take the square root of two and two-thirds times that length, or, to express it in a formula:

$$S = \sqrt{2\tfrac{2}{3} \times z}\,.$$

Rule 3.—When the speed does not exceed the limit given by Rule 2, to find the probable resistance in pounds: measure the mean immersed girth of the ship on her body plan; multiply it by her length on the water line; then multiply by 1 + 4 (mean square of sines of angles of obliquity of stream lines). The product is called the augmented surface. Then multiply the augmented surface in square feet by the square of the speed in knots, and by a constant coefficient; the product will be the probable resistance in pounds. To express this in formulae:

$$A = L \times G \times [1 + 4\,(\sin\, y)^2], \text{ and}$$
$$R = A \times S^2 \times C\,.$$

Where A = augmented surface in square feet, L = length in feet on water line, G = mean immersed girth in feet on body plan, y = mean of the greatest angles of obliquity of all water lines to the keel, S = speed, and C = a constant coefficient, the values of which may be given as 0.01 for clean painted iron vessels, 0.009 to 0.008 for clean coppered vessels, and 0.011 and upwards for moderately rough iron vessels.

Rule 4.—To estimate the net or effective horse-power expended in propelling the vessel, multiply the resistance by the speed in knots, and divide by 326, or

$$\text{Net I. H. P. for propulsion of ship} = \frac{A \times S^3 \times C}{326}\,.$$

Rule 5.—To estimate the gross or indicated horse-power required, divide the same product by 326, and by the combined efficiency of engine and propeller. In ordinary cases that efficiency is from 0.6 to 0.625, say an average of 0.613; therefore in such cases the preceding product is to be divided by 200 (Rankine, Rules and Tables) or,

$$\text{Gross I. H. P. developed by engines} = \frac{A \times S^3 \times C}{200}.$$

These rules give very accurate results but are tedious and require the lines to be fully drawn before the calculations for I. H. P. can be made.

For a fuller discussion of the foregoing three rules, *A*, *B* and *C*, see Seaton's Manual of Marine Engineering, 1896, White's Naval Architecture, and Journal of Naval Engineers, Vol. iii, No. 4.

D.—FROUDE'S LAW.

Froude's law for comparing ships and models of similarly proportioned vessels of different sizes (see White's Naval Architecture) is as follows:

The resistances vary as the cubes of the similar dimensions (length, say), and the speeds vary as the square roots of the similar dimensions. To express it in formulae

$$\frac{R'}{R} = \left(\frac{L'}{L}\right)^3, \qquad \text{and } \frac{S'}{S} = \sqrt{\frac{L'}{L}},$$

where R and R′ are the resistances, S and S′ the speeds, and L and L′ the lengths.

In similar vessels, the cube of the ratio of similar dimensions is equal to the ratio of the displacements, or

$$\left(\frac{L'}{L}\right)^3 = \frac{D'}{D}, \qquad \text{therefore } \sqrt{\frac{L'}{L}} = \sqrt[6]{\frac{D'}{D}}.$$

From these we see that the

Ratio of speeds of two similar vessels $= \frac{S'}{S} = \sqrt[6]{\frac{D'}{D}}$; and that the

Ratio of dimensions of two similar vessels $= \frac{L'}{L} = \sqrt[3]{\frac{D'}{D}}$; and that the

Ratio of ⊕ (immersed midship section) of two similar vessels $= \left(\frac{D'}{D}\right)^{\frac{2}{3}}$; and that the

Ratio of I. H. P. of two similar vessels $= \frac{D'}{D}\sqrt[6]{\frac{D'}{D}}$;

in all of which D and D′ are the displacements.

Comparing the Yorktown data with the Cincinnati, we have

D′ (Cincinnati) 3183 tons.
D (Yorktown) 1680 tons.

$$\frac{D'}{D} = 1.8946.$$

$$\text{Ratio of speeds} = \sqrt[6]{\frac{D'}{D}} = 1.1124.$$

$$\text{Ratio of dimensions} = \sqrt[3]{\frac{D'}{D}} = 1.2374.$$

$$\text{Ratio of } \oplus = \left(\frac{D'}{D}\right)^{2/3} = 1.5311.$$

$$\text{Ratio of I. H. P.} = \frac{D'}{D}\sqrt[6]{\frac{D'}{D}} = 2.1076.$$

The Yorktown's dimensions are: length 223′; beam 36′; draft 14′; dead flat section 435 square feet.

The dimensions of a vessel similar to the Yorktown but about the size of the Cincinnati would be: length 282′; beam 44′ 6″; draft 17′ 3-1/2″; dead flat section 665 square feet.

Therefore, if the Yorktown's speed was 16.14 knots, with 3205 I. H. P., the Cincinnati's speed would be 16.14 × 1.1124 = 17.95 knots, with 3205 × 2.1076 = 6755 I. H. P.

If we assume that the I. H. P. varies as $S^{3.5}$ at high speeds, we would have,

$$\overline{17.95^{3.5}} \; : \; \overline{20^{3.5}} \; :: \; 6755 \; : \; Z,$$

whence Z = I. H. P. necessary to drive Cincinnati 20 knots = 9863.

This is the I. H. P. necessary for a vessel of the displacement of the Cincinnati, but similar to the Yorktown, the dimensions being as found above. As the Cincinnati is, however, a longer ship than the expanded Yorktown, it is probable that less I. H. P. will suffice for 20 knots.

In this rule it is necessary to have accurate data of a similarly proportioned vessel to work from, having which, the results will be very close. From the data obtained as above for different speeds, a speed and power curve can be laid down for the new vessel.

This rule assumes all frictions as constant percentages of the effective or propelling H. P., which is nearly accurate in practice.

The I. H. P. of the main engines only would ordinarily be used, though, as the auxiliaries form nearly a constant percentage, it does not matter much whether we use the gross or the net I. H. P.

It is well to compare the coefficients of fineness of the old and of the proposed vessel also, which is

$$C = \frac{D \times 35}{L \times B \times d},$$

(where C is the coefficient of fineness, D is displacement, L is length between perpendiculars, B is beam and d is draft), especially for high speeds, and also to compare the lengths, as it may be shown that the size of the proposed vessel may be advantageously changed for the proposed speed.

The data of several vessels should be worked up to find data for the proposed vessel, and then either the average or the most reliable data taken.

In rules *A* and *B* heretofore given, if the constants are chosen from reliable data from trials of ships of about the same shape, size and speed as the proposed vessel, the results will be quite reliable.

E.—KIRK'S ANALYSIS.

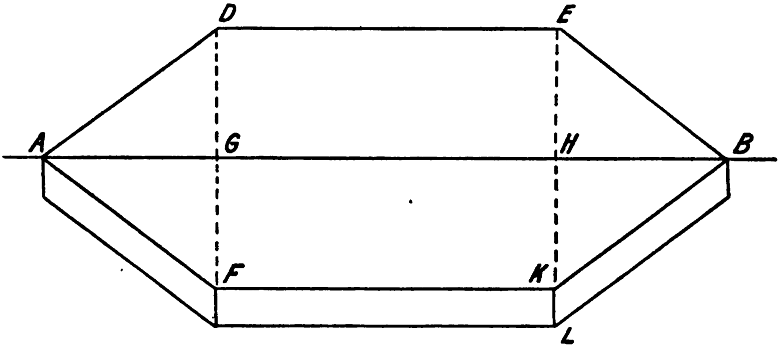
A fairly reliable method, and one of the readiest, is known as Kirk's Analysis. (See Seaton.)

The general idea in this analysis is to reduce all ships to so definite and simple a form that they may be easily compared; and the magnitude of certain features of this form shall determine the suitability of the ship for speed, etc. As rectangles and triangles are the simplest forms of figures, and more easily compared than surfaces enclosed by curves, so the form chosen is bounded by triangles and rectangles.

The form consists of a middle body, which is a rectangular parallelopiped, and the fore body and after body, which are prisms having isosceles triangles for bases; in other words, it is a vessel having a rectangular midship section, parallel middle body, and wedge-shaped ends, as shown in the figure.

This is called a block model, and is such that its length is equal to that of the ship, the depth is equal to the mean draft of water, the capacity equal to the displacement, and the area of section equal to the area of the immersed midship section of the ship. The dimensions of the block model may be obtained by the following methods, the figures being those of the Cincinnati:

In the figure, since AG is supposed to equal HB, and DF equals EK, the triangle ADF equals the triangle EBK, and they together will equal the rectangle whose base is DF and height is AG. Therefore, the area ADEBKF equals EK × AH. The volume of the figure is this area multiplied by the height KL. Then the volume of the block is equal to KL × EK × AH. But KL × EK is equal to the area of mid section, which is assumed to be equal to the area of immersed midship section of the ship, and the volume of the block is equal to the volume displaced by the ship. Hence



$$\text{Displacement} \times 35 = \text{immersed midship section} \times AH;$$

or

$$AH = \text{displacement} \times 35 \div \text{immersed midship section.}$$

Now

$$HB = AB - AH, \text{ and } AB = \text{the length of the ship.}$$

Therefore the length of the fore body of block model is equal to the length of the ship, less the value of AH as found above.

Again, the area of the section KL × EK is equal to the area of immersed midship section, and KL is equal to the mean draft of water. Therefore

$$EK = \text{immersed midship section} \div \text{mean draft of water.}$$

It has also been found that the wetted surface of this block model is very nearly equal to that of the ship; and as this area is easily calculated from the model, it is a very convenient and simple way of obtaining the wetted skin. In actual practice, the wetted skin of the model is from 2 to 5 per cent in excess of that of the ship; for all purposes of comparison and general calculation it is sufficient to take the surface of the model.

$$\text{Area of bottom of model} = EK \times AH.$$

$$\text{Area of sides} = 2 \times FK \times KL = 2(AB - 2HB) \times KL = 2\,(\text{length of ship} - 2\text{ length of fore body}) \times \text{mean draft of water}.$$

$$\text{Area of sides of ends} = 4 \times KB \times KL = 4\sqrt{\overline{HB}^2 + \overline{HK}^2} \times KL = 4\sqrt{\text{Length of fore body}^2 + \text{half breadth of model}^2} \times \text{mean draft of water}.$$

The angle of entrance is EBK; EBH is half that angle; and the tangent of EBH = EH ÷ HB.

Or, tangent of half the angle of entrance = half the breadth of model ÷ length of fore body.

From this the angle of entrance may be obtained.

The block model for ocean-going merchant steamers, whose speed is from 14 knots upward, has an angle of entrance of from 18 to 15 degrees, and a length of fore body from 0.3 to 0.36 of the length.

That of ocean-going steamers whose speed is from 12 to 14 knots has an angle of entrance from 21 to 18 degrees, and a length of fore body from 0.26 to 0.3 of the length.

That of cargo steamers whose speed is from 10 to 12 knots has an angle of entrance from 30 to 22 degrees, and a length of fore body 0.22 to 0.26 of the length.

To find the I. H. P. from the wetted surface.—In ordinary cases, where steamers are formed to suit the speed as indicated above, the number of horse-power per 100 square feet of wetted surface may be found by assuming that the rate for a speed of 10 knots per hour is 5, and that the quantity varies as the cube of the speed. When the ship is exceptionally well proportioned, the bottom quite clean, and the efficiency of the machinery high, as low a rate as 4 horse-power per 100 square feet of wetted skin of block model may be allowed.

Applying this to the Cincinnati, we have

AB = length between perpendiculars = 300′
KL = mean draft = 18′
The cubic contents = displacement = 3183 tons.
EK × KL = immersed midship sections = $\oplus$ = 665 sq. ft.

$$AH = \frac{\text{displacement} \times 35}{\oplus} = \frac{3183 \times 35}{665} = 167.53$$

Length of fore body =

$$HB = AB - AH = 300' - 167'.5 = 132'.5$$

$$EK = \frac{\oplus}{KL} = \frac{665}{18} = 36'.944 \quad \therefore \quad EH = \frac{EK}{2} = 18'.47$$

$$EB = \sqrt{EH^2 + HB^2} = \sqrt{18.47^2 + 132.5^2} = 133.78$$

Angle of entrance $= EBK$ and tang. $EBH = \frac{EH}{HB} = \frac{18.47}{132.5}$
$= \text{tang. } 7°56'$

$\therefore$ angle $EBK = 2 \times 7°56' = 15°52' =$ angle of entrance.

Seaton says for speeds above 14 knots $EBH = 18°$ to $15°$ and that $HB = 0.3$ to 0.36 of AB. For Cincinnati $HB = 0.44$.

Wetted surface $= EK \times AH + 2\ FK \times KL + 4 \times EB \times KL = 36.944 \times 167.5 + 2\ (300 - 2 \times 132.5) \times 18 + 4 \times 133.78 \times 18 = 17080.28$.

$\therefore$ wetted skin of ship $=$ wetted surface of block $\times \frac{100}{107} +$ surface of bilge keels less skin surface covered by them.

$$= 17080 \times \frac{100}{107} + 2\ [2 \times 2 \times 200 - 1/2 \times 200]$$
$$= 15962 + 1400 = 17362 \text{ sq. ft.}$$

For 100 sq. ft. wetted skin it requires 4.5 I. H. P. to drive it 10 knots.

$\therefore$ for 20 knots I. H. P. $= \left(\frac{20}{10}\right)^{3.5} \times 4.5 = 51.$

$\therefore$ for 17362 sq. ft. of wetted skin it requires for 20 knots $173.62 \times 51 = 8855$ I. H. P.

From the foregoing rules we have the following results for estimated I. H. P. of main engines of Cincinnati to drive her 20 knots:

Rule	*A.*—9617	I. H. P.
"	*B.*—9672	I. H. P.
"	*D.*—9863	I. H. P.
"	*E.*—8855	I. H. P.
	Average, 9502	I. H. P.

The I. H. P. of all auxiliary engines averages about 3.5% of the I. H. P. of main engine; $\therefore$ for the Cincinnati

total I. H. P. $= 9502 \times 1.035 = 9835$, or say 10,000.

Question No. 2.—Calculate the dimensions of cylinders for a given horse-power.

To calculate the dimensions of cylinders for a given I. H. P. we calculate the area of the L. P. cylinder as if all the work was to be performed in that cylinder.

Assume the following data:

Working pressure of steam = P; then the absolute pressure = P + 14.7. Total ratio of expansion of steam = R; cut-off in H. P. cylinder = C;

The stroke of the piston and the number of revolutions give the piston speed. The back pressure in the cylinder varies from 2-1/2 to 6 lbs. per sq. in.

Let p = the initial, p_m = the mean forward, and p_e = the mean effective pressure.

For a ratio of expansion R, $p_m = \frac{1}{R}(1 + \log_e R) \times p$:

For values of p, see Seaton, p. 118.

In the above expression $\log_e R = \log_{10} R \times 2.30258$.

On account of the drop in pressure in the pipe leading to the H. P. cylinder and of the wire drawing of the steam through the ports, the initial pressure in that cylinder is far below the boiler pressure; the Newark and Concord showing a loss of about 28 lbs. There is also a considerable drop in the pressures in the receivers, so that only about 60% of the mean pressure due to the initial pressure can be calculated on; so we have,

$$p_e = p_m \times .60 - \text{back pressure in cylinder.}$$

∴ Net area of L. P. cyl. =

$$\frac{\text{I. H. P.} \times 33000}{\text{piston speed per minute} \times \text{mean eff. pres.}}$$

To this area we add one-half the area of the piston rod, and from the resulting area we obtain the diameter of the cylinder.

In order to get the true expansion we must consider the clearance in the H. P. cylinder: this for slide valves is about 12%, and for piston valves about 22% of the piston displacement.

$$\therefore \text{Actual ratio of expansion in H. P. cyl.} = \frac{\text{Stroke} + \text{clearance}}{\text{Cut-off} + \text{clearance}}$$

$$\therefore \frac{\text{Area of L. P. cyl.}}{\text{Area of H. P. cyl.}} = \frac{\text{total ratio of expansion}}{\text{ratio of expansion in H. P. cyl.}}$$

∴ Area of H. P. cyl. =

$$\frac{\text{Area of L. P. cyl.} \times \text{ratio of expansion in H. P.}}{\text{total ratio of expansion}}.$$

Seaton gives the following formulae:

$$\text{Area H. P. cyl.} = \frac{\text{Area L. P. cylinder}}{\text{Cut-off in H. P. cyl.} \times \text{total ratio of expansion}}.$$

For triple expansion engines,

$$\text{Area I. P. cyl.} = \frac{\text{Area of L. P. cylinder}}{1.1 \sqrt{(\text{ratio of area of L. P. to H. P.})}}.$$

For quadruple expansion engines, the ratio between any two adjacent cylinders =

$$\sqrt[3]{\left(\frac{\text{Area L. P. cylinder}}{\text{Area H. P. cylinder}}\right)}.$$

For triple expansion engines, the Bureau of Steam Engineering makes the I. P. cylinder a little less than a mean proportional between the H. P. and L. P. cylinders, or

$$\text{Area I. P. cyl.} = \text{Area H. P. cyl.} \sqrt{\left(\frac{\text{Area L. P. cylinder}}{\text{Area H. P. cylinder}}\right)}.$$

Taking the Cincinnati, we have I. H. P. of one engine $= \frac{9502}{2} =$ 4751.

Boiler pressure = 160 lbs. = 174.7 absolute; allowing for drop to initial pressure in H. P. cylinder we have $p_1 = 174.7 - 28.7 =$ 146 lbs.

Speed of piston $= 2 \times \frac{33}{12}$ stroke × 164 revolutions per minute = 902 ft. per minute.

Cut-off in H. P. cyl. = 7/10 stroke, and the back pressure =3 lbs.

Where weight and space are of such importance as they are in naval vessels, economy is not given the same consideration as it is in engines of the merchant marine, and for boiler pressures of 160 pounds, the ratio of L. P. to H. P. cylinder is generally made 5.0. Assume such a ratio and a clearance of 20 per cent. Then the actual rate of expansion in H. P. cylinder will be $\frac{1 + .20}{.7 + .20} =$ 1.333, and the total rate of expansion for the engine $5 \times 1.333 =$ 6.66, for which $\frac{p_m}{p_1} = .4347$.

$\therefore p_m = 146 \times .4347 = 63.5$.

$\therefore p_e = 63.5 \times .60 - 3 = 35$ lbs. = mean effective pressure.

$\therefore$ net area of L.P. cyl. $= \frac{4751 \times 33000}{902 \times 35} = 4966$ sq. ins.

or, net area of each of the two L. P. pistons = 2483 sq. ins.

This corresponds to a diameter of 56.22 inches, without considering the piston rod; say 57 inches as the diameter of each piston, and a corresponding total area of L. P. piston = 2553 sq. ins.

Actual ratio of expansion in H. P. cyl. $= \frac{1 + .20}{.7 + .20} = 1.33$.

$\therefore$ Area of H. P. cyl. $= \frac{2 \times 2553 \times 1.33}{6.66} = \frac{2 \times 2553}{5} =$ 1021 sq. ins. which gives a cylinder of 36″ diameter.

By Bureau of Steam Engineering rule: Area I. P. cyl =

$$1021 \sqrt{\left(\frac{2 \times 2553}{1021}\right)} = 2277 \text{ sq. ins.}$$

corresponding to a diameter of 53.8″; as the Bureau makes it a little less than the mean proportional, say 53″.

Using Seaton's rules:

Area H. P. cyl. $= \frac{2 \times 2553}{.7 \times 6.66} = 1095$ sq. ins., which gives 37.3″ diam.

Area I. P. cyl. $= \frac{2 \times 2553}{1.1\sqrt{\left(\frac{2 \times 2553}{1021}\right)}} = 2082$ sq. ins., which gives 51.5″ diam.

Question No. 3.—Calculate the dimensions of condensers and pumps for engines of given dimensions.

CONDENSERS.—The Bureau of Steam Engineering rule is to have 1.4 square feet of tube cooling surface for each I. H. P. The condenser should be large enough to condense the steam from the main and from all auxiliary engines, hence we use the total I. H. P.

The total tube surface in square feet = 1.4 × I. H. P.

Let the tubes be 5/8″ outside diameter and 11′6″ long between the tube sheets, giving for one tube a cooling surface of 1.8817 sq. ft.

$\therefore$ for Cincinnati, the number of tubes $= \frac{1.4 \times 5000}{1.8817} = 3720$.

The condensers of that ship each have 3715 tubes of above size.

It is the usual practice in our service to space 5/8-inch tubes 15/16 inch from center to center, and to make the condensers cylindrical. The diameter for such a condenser would be determined from a diagram giving the number of tubes that can be put in a cylinder of a given diameter. An approximate rule for this is to divide the number of tubes by 144; the result will be the area in square feet of a circle whose diameter will be the diameter of the condenser.

The condenser should be made in three sections, the center one carrying all the nozzles, if practicable. The injection water should enter and leave at the same end of the condenser, whose total length will be about 2 feet greater than that of the tubes.

AIR PUMPS.—The Bureau of Steam Engineering allows about 2/10 cu. ft. displacement per minute per I. H. P.

$5000 \times .2 = 1000$ cu. ft. per min. displacement. Assume stroke $= 16\text{-}1/2'' = 1.375'$, revolutions $= 100$ per minute, and that the pump is to be single acting.

$$\therefore \frac{1000}{1.375 \times 100} = 7.27 \text{ sq. ft.} = 1047 \text{ sq. ins. area of pistons.}$$

Using a two-cylinder pump we have $\frac{1047}{2} = 523.5$ sq. ins. for each piston, corresponding to a diameter of 25.85 in., say 26 in.

The pumps should then be 26-in. diameter by 16-1/2-in. stroke.

Assume the pressure on the air-pump piston to be 25 lbs. per sq. inch and on the steam piston 100 lbs. per sq. inch and we have

The area of steam piston = area air-pump piston × 1/4.

To this add 25% for friction and we have area of the steam pistons $= 524 \times 1/4 \times 1.25 = 163.75$ sq. ins. $= 14.4''$ diameter.

The displacement of the air pump is sometimes calculated as being one-thirtieth of the displacement of the L. P. piston in the same unit of time.

Assuming same stroke and piston speed as above, for a two-cylinder pump, which gives $\frac{2 \times 2483 \times 902}{30 \times 1.375 \times 2 \times 100} = 542.96$ sq. ins. area of each piston corresponding to a diameter of 26.3 ins.

Seaton gives for a vertical, single-acting pump for triple-expansion engines with surface condenser, a capacity of 1/23 that of the L. P. cylinder. Using this value, would give

$$\frac{2 \times 2483 \times 33 \times 2}{23} = 14{,}250 \text{ cu. ins.}$$

With a stroke of 16-1/2 inches, and two pump cylinders, the area of each piston would be

$$\frac{14250}{2 \times 16.5} = 431.8 \text{ sq. ins.}$$

This corresponds to a piston 23-1/2 inches diameter, and would be for a pump worked from the main engine.

CIRCULATING PUMPS.—Most modern ships use centrifugal circulating pumps.

The Bureau of Steam Engineering allows 2 gallons of water per minute per I. H. P. On this assumption the Cincinnati should have $5000 \times 2 = 10000$ galls. delivered per minute,

$= 80000$ lbs.

Say it is delivered against a head of 10 ft., then the I. H. P. of engine for pump $= \frac{10000 \times 8 \times 10}{33000} = 24$.

The above is for separate air and circulating pumps. If these pumps are to be combined, as is often done, the total I. H. P. may be diminished a little by properly designing the pumps, the circulating pump being then made a double-acting pump of sufficient capacity to deliver the above amount of water.

If we calculate the necessary amount of injection water to abstract the heat of the exhaust steam, we assume the exhaust pressure, say 10 lbs. absolute; the pounds of steam per I. H. P., say 20 lbs. per hour, and the difference of temperature between injection and discharge water, say 20° F.,

$$\frac{5000 \times 20 \text{ (lbs. steam)} \times 1052 \text{ (heat in a pound of steam)}}{20^\circ \times 60 \times 8\text{-}1/3 \text{ (weight of a gall. salt water)}}$$

$= 10524$ galls. per minute (maximum), from which we get

$\frac{10524}{7.5} = 1400$ cu. ft., say.

Allowing 1000 ft. per minute for the velocity of the water; area of inlet $= \frac{1400}{1000} = 1.4$ sq. ft., or 16″ diam.

If we use a centrifugal pump and make the diameter 2-1/2 times the inlet, we have a pump of 40″ diameter. This pump running at about 250 revolutions per minute, will deliver this amount of water.

Seaton says the velocity of water should not exceed 400 ft. per min.; ∴ the diam. of pipes $= \sqrt{\frac{\text{galls. per min.}}{16.3}}$, and the velocity of the periphery of the fan should be about 500 ft. per min.

In centrifugal pumps, the water should enter the pump on both sides of the fan, so as to balance it, and not draw or force the fan against one side of the casing; or else thrust collars should be fitted on shaft to accomplish the same object.

FEED PUMPS.—The total quantity of feed water required will be 20 lbs. per hour per I. H. P., and, doubling this for emergencies and to allow for slip and leakage, we must have in each engine room a main feed pump of capacity =

$$5000 \times 20 \times 2 = 20000 \text{ lbs. per hour.}$$
$$= 53 \text{ cu. ft. per minute.}$$

If the stroke = 1′ and we have 100 strokes per min., the pumps must deliver:

$$\frac{53}{1 \times 100} = .53 \text{ cu. ft. per stroke.}$$

∴ 144 × .53 = 76 sq. ins. = area of piston, and the diameter = 9.8″.

If the pump be double acting, $\frac{76}{2} = 38$ sq. ins. = area of piston, corresponding to a diam. of 7″.

If we use a duplex pump, the area of each of the pistons is 1/2 that of a single-cylinder pump.

Make the area of steam to water piston 2-1/4 to 1.

Question No. 4.—Calculate dimensions of a set of boilers to furnish steam for a given horse-power.

For maximum power, forced draft will be used, and then the boilers should develop 16.4 I. H. P. per square foot of grate surface (see trial of Newark).

$$\therefore \text{ grate surface} = \frac{10000}{16.4} = 610 \text{ sq. ft.}$$

We will make the grates 6′ long and the furnace flues 42″ inner diam. ∴ one furnace = 21 sq. ft., and the number of furnaces = $\frac{610}{21} = 29$: say 30.

We will use 4 double-ended boilers 14′ in diam. (provided space will allow), having three furnaces in each end, and two single-ended 3-furnace boilers of same size.

Length will be = 2 (length of grate + thickness of bridge wall + depth of back connection + thickness of heads and combustion chambers) + water space between connections.

$$= 2\,(6' + 1' + 2'\,6'' + 1\text{-}1/4'' + 3/4'') + 6'' =$$
$$2 \times 9'8'' + 6'' = 19'10''.$$

Heating surface = grate surface × 31 to 35, or I. H. P. × 1.887 = 610 × 33 = 20130 sq. ft. or = 18870 sq. ft. (Newark).

The heating surface per I. H. P. for later vessels = 1.7 to 2.3 sq. ft. Tubes should be 2-1/4″ outside diameter, and about 7′6″ long.

Calorimeter through tubes should be 1/6 to 1/8 of the grate surface. ∴ number of tubes in one double-ended boiler =

$$\frac{21 \times 6}{7} \times \frac{144}{3.1416} = 824.$$

If the space to be occupied in the ship be given, the boilers can be laid down on paper to see if they will fit in, or, by using the tables in Seaton, we can tell whether the designed boilers will fit in the given space.

The distribution of the heating surface is about as follows: tubes = 86.3%, furnaces = 6.4%, connections = 7.3%.

The steam space (total) should be such that it equals the volume of steam used in 20 seconds by the engines, in order to avoid foaming; or there should be 55/100 cu. ft. of steam space per I. H. P.

The top row of tubes should not be less than 1/3 the diameter of the boiler from the top.

WATER-TUBE BOILERS.

The great number of types of water-tube boilers in existence makes it impossible to lay down any general rules for their design. The H. P. per foot of grate surface, and the proportion of heating surface to grate surface are very variable, even in boilers of the same type. The following table shows this, and gives about all the information possible relative to the proportions with which a water-tube boiler should be built.

Type of boiler.	H. P. per sq. ft. of grate.	Heating surface per sq. ft. of grate.
Babcock & Wilcox	12 to 15	30 to 45
Niclausse...............	10 to 18	30 to 40
Belleville......	11 to 18	27 to 37
Normand...............	20 to 32	50 to 58
Thornycroft	20 to 30	48 to 70
Yarrow.................	20 to 30	50 to 55

These figures are very rough approximations, so much will depend upon the conditions under which they are used.

In designing a boiler, the items in this table must be known, and the exact values of them to be used must be determined by experience with the particular type in view.

Then, knowing the H. P. desired, the number of feet of grate surface is taken from the table, and the shape of the grate determined to suit the general dimensions allowed for the boiler, the method of arranging tubes, etc.

Then the third column of the table will give the number of feet of heating surface, and to calculate the number of tubes, etc., the development of the different sets of curved tubes must be known, from which the calculation can be readily made.

It is not possible to give more definite rules for water-tube boiler design than these, but the calculations are simple, although long, and the points here indicated should be sufficient as a general guide.

Question No. 5.—Calculate the dimensions of propellers to drive a vessel at a given speed.

The slip of the screw varies from 10 to 20% at high speeds. Let S = speed of ship in knots, and R = revolutions of engine per minute:

$$\text{Feet travel of ship per minute} = \frac{S \times 6080}{60}.$$

$$\text{Feet travel of ship per revolution} = \frac{S \times 6080}{60} \times \frac{1}{R}.$$

$$\text{Pitch of screw in feet} = \frac{S \times 6080}{60} \times \frac{1}{R} \times \frac{100}{(100\text{—per cent of slip})}$$

$$\text{or } P = \frac{S}{R} \times \frac{10133}{(100\text{—per cent of slip})}.$$

The diameter of the screws varies according to each ship; the tips of the blade should be at least two feet under water and, for twin screws, should clear the sides of the ship by at least a foot. A small diameter of screw for high-speed engines is preferable, as it reduces the velocity of the tips of the blades, thus reducing the loss by friction, but the diameter must not be too small or the area of the blades will not be sufficient to take up the power of the engines.

The Bureau of Steam Engineering allows about 1000 lbs. mean normal thrust per square foot of helicoidal area of the blades.

Twin screws should be placed so that the centers of length of hubs will be at least 1/5 the diameter of the propellers forward of the rudder post.

The pitch is usually from 1 to 1-1/2 times the diameter.

We have,

Feet travel of ship per minute $= \dfrac{S \times 6080}{60}$, and

Foot pounds exerted by engines per minute $=$ I. H. P. $\times$ 33000.

Therefore the number of foot pounds exerted by engines for each foot travelled by ship $= \dfrac{\text{I. H. P.} \times 33000}{S \times \dfrac{6080}{60}}$.

If we assume that 1/3 of the I. H. P. goes to other purposes than propelling the ship, then we have

The mean normal thrust $=$

$$\frac{2}{3} \times \frac{\text{I. H. P.} \times 33000}{S \times \dfrac{6080}{60}} = 217 \times \frac{\text{I. H. P.}}{S}.$$

From this we see that the thrust varies as the I. H. P. and inversely as the speed, so that it may vary considerably under different conditions, as when the engine first moves, or when the ship is towing or driving against a head wind or sea. In these cases the actual thrust will exceed the mean normal thrust and must be provided for in designing the thrust bearing.

Seaton gives the following formulae:

Diameter of propeller in feet $=$

$$K \sqrt{\frac{\text{I. H. P.}}{(P \times R)^3}} \qquad \text{where } K = 20000 \text{ to } 25000.$$

Total area of blades in sq. ft. $=$

$$K \sqrt{\frac{\text{I. H. P.}}{R}} \qquad \text{where} \left\{ \begin{array}{l} K \text{ for four-bladed screws is 15 for} \\ \quad \text{single and 10.5 for twin screws.} \\ K \text{ for three-bladed screws is 13 for} \\ \quad \text{single and 9.0 for twin screws.} \\ K \text{ for two-bladed screws is 10 for} \\ \quad \text{single screws.} \end{array} \right.$$

These values of K in the formula for the area of the blades apply rather to merchant vessels of moderate speed than to naval vessels of high speed, for which the values are much less, varying from 11.5 to 10.5 for four-bladed, and from 9.0 to 7.0 for three-bladed screws at speeds of 16 to 22 knots.

The maximum breadth of blade should be at 1/2 radius of screw from the center, and =

$$C\sqrt[3]{\frac{\text{I. H. P.}}{\text{R}}} \quad \text{where} \begin{cases} \text{C for four-bladed screws} = 14 \\ \text{C for three-bladed screws} = 17 \\ \text{C for two-bladed screws} = 22 \end{cases}$$

The width of the tip of the blade should be 1/3 to 2/5 of the maximum breadth. Diameter of boss = 1/4 to 1/5 the diameter of screw.

The helicoidal area of all the blades is sometimes calculated from the area of the immersed midship section, and =

$$\frac{\oplus}{5.5}$$

For the Cincinnati, assuming 20% slip, we have

$$\text{Pitch} = \frac{20 \times 100 \times 6080}{60 \times 164 \times (100 - 20)} = 15'.5 = 15'6''.$$

Assuming two extremes, we have

$$\text{Diam.} = 24000\sqrt{\frac{5000}{(15.5 \times 164)^3}} = 13.25 \text{ feet},$$

$$\text{Diam.} = 25000\sqrt{\frac{5000}{(15.5 \times 164)^3}} = 13.8 \text{ feet},$$

or Diam. (mean) = 13.5 feet, and for area of blades

$$\text{Area} = 8\sqrt{\frac{5000}{164}} = 44.1 \text{ sq. ft.},$$

$$\text{Area} = 8.5\sqrt{\frac{5000}{164}} = 46.9 \text{ sq. ft.}$$

Area (mean) = 45.5 sq. ft.

$$\text{Mean normal thrust} = 217 \times \frac{5000}{20} = 54250 \text{ lbs.}$$

Allowing 1000 lbs. per sq. ft. as used by Bureau of Steam Engineering, we have that the area of blades = 54.25 sq. ft., say 50 sq. feet.

$$\text{Indicated thrust} = \frac{5000 \times 33000}{15.5 \times 164} = 64900 \text{ lbs., about.}$$

$$\text{Maximum breadth of blade} = 17\sqrt{\frac{5000}{164}} = 53''$$

$$\text{Diameter of boss} = \frac{13'.5}{5} = 2.7'.$$

Using immersed midship section, we have

Area of all blades for 2 screws $= \frac{665}{5.5} = 121$ sq. ft.

or for each screw $\frac{121}{2} = 60.5$ sq. ft.

The actual screw has 50 sq. ft. helicoidal area.

Subject No. 2.—Duties as Chief Engineer of a Ship in Commission.

Question No. 1.—What procedure should be adopted on joining a ship to ascertain that the machinery is in proper condition; that is, what parts should be inspected, and how can the needed information be best secured in the shortest time?

In order to ascertain as quickly as possible the condition of the machinery of a ship relative to which there is no reliable information available, detail working gangs under the machinists and boiler makers, and make as thorough an examination of the following parts as time will allow:

Open all cylinders, examine piston-rod nuts and packing boxes of piston rods and valve stems, piston packings and bolts, wearing surfaces, valves and seats, core plugs in cylinders and pistons, and the steam and exhaust ports. Remove caps and top brasses of all main journals, of shafting and cross heads, and see that they are in good condition, and also make sure that the bearings are properly set up.

If gauge marks are on the bed plates or seatings, see that the shafts are in proper line.

Examine thrust bearings by removing cap or thrust rings.

Examine stern stuffing boxes, to see if shafts have worn down and that packing is in good condition.

See that all joints or gaskets are in good condition.

In order to make these examinations quickly, such parts as are accessible with the engines in one position should be examined at the same time.

Test the boilers with hydrostatic pressure by heating the water. Afterwards open all the boilers and examine them closely for corrosion, giving a hammer test.

Particular care should be taken in examination of tubes and brace fastenings. Examine all the valves, see that proper ones are on the boilers, and that all gauges are properly connected.

Examine all main and auxiliary pumps and machinery.

Examine condensers by putting test pressures on each side of tubes.

Test steam and water piping if possible, and see that proper drains are fitted on all piping.

Get up steam and try pumps and auxiliary machinery. Then run the main engines, taking care to see how the valves are set.

Question No. 2.—How should the men of the engineer's force be stationed for steaming watches and for general and fire quarters? (The examining board gives the number of the engines and auxiliaries, and of the boilers, with an idea of the general arrangements as regards subdivision. With these data given, the candidate must state the number of men required and their assignment.)

To station the engineer's force for steaming watches the number of men of each rate should be divided into three parts to form the three divisions, care being taken that each watch is as nearly equal in the quality of the men composing it as possible.

For twin-screw vessels there should be in each watch a machinist stationed in each engine room for working the main engines, and one to take charge of the air, circulating and feed pumps, and all other auxiliary machinery in the engine or condenser compartments.

If there be an upper and lower engine room for each main engine, an oiler should be stationed in each, and if the parts of the engines are difficult of access, there should be two oilers around those parts.

An oiler should also be stationed at the auxiliary machinery in engine and condenser compartments of each engine. There should be a water tender in each fire room (boiler makers and blacksmiths should do duty as water tenders at sea, when not required for work on boilers) to have charge in that fire room over pumps, blowers, etc.

There should be one first-class fireman and one second-class fireman to each four furnaces, and at least three coal passers for the same number of furnaces, as in modern ships the coal bunkers are mostly pockets to which access is not easy, necessitating considerable handling of coal before it is put on the fire-room floor.

There should be one man (a second-class fireman) detailed in each fire room that has a blower and feed pump, to look after and oil them while running.

There should be a water tender or oiler on watch at the distilling plant; and an oiler at the steering engine and to oil and look out for any working machinery outside of the engine and fire rooms not mentioned above. One of the firemen in each fire room should be detailed to run the ash-hoisting engines.

Hence the total number of men in the engineer's force should be three times the above, besides a yeoman and store room keeper.

FOR GENERAL AND FIRE QUARTERS.—The division on watch should remain at their stations.

The machinists and oilers of the first relief watch should go to their stations in engine rooms and condenser rooms, and should see that all water-tight doors in those compartments are closed; that all fire pumps are started and working slowly overboard, ready to send water to hose; and should then lead out the engine-room fire hose.

The yeoman and store room keeper should see that all store rooms and workshops are closed.

The machinists of the second relief division should take charge of the port and starboard hose, the oilers to couple on the hose (if not kept coupled on).

The water tenders of the first relief division should go to their stations in the different fire rooms, to see that all doors are closed, viz.: air locks, doors from one fire room into another, and all doors in and into bunkers. The first and second-class firemen of this division should assist in closing doors. The relief water tenders should have charge of the fire pumps, should start them running slowly overboard, should see that everything is ready to turn water on hose, and should then lead out the fire-room hose.

The water tenders of the second relief division should take charge of the nozzles of the different fire hose, the firemen of their division from their fire room assisting in leading out the hose. If there are not enough oilers for coupling on the different fire hose, first-class firemen should take their places.

The boiler makers and blacksmiths should take charge in the main fire rooms.

The ventilating engines on the berth deck should be stopped by the machinists of the second relief division in case of fire.

The coal passers should be stationed with the firemen, unless ordered by the commanding officer for duty in powder division.

In making out any bill, each man should be given his special work, as closing certain doors, etc.

Question No. 3.—Give a statement of points to be observed in caring for machinery and the precautions to be observed (a) when in use; (b) and when not in use, in order to insure its readiness for service.

While the machinery is running, special care should be taken to see that all working parts are constantly oiled (sight-feed cups being the best way) and that the oil cups are working properly.

All journals and slides should be felt every 15 or 20 minutes for signs of heating.

Any slackness of journals, due to working loose of nuts, etc., should be immediately remedied if possible, even if it be necessary to stop the engine. The drains must all be kept clear around the engines. All packing showing leaks must be set up.

The boiler safety valves should be raised once a watch. All gauge cocks should be tried every 30 minutes, and all glass gauges should be blown out every watch.

No wet ashes should be allowed in contact with boilers.

When the machinery is not in use, the cylinders should be examined after every run, follower bolts examined, and the cylinder walls wiped dry and oiled with thin cylinder oil or vaseline. The packing should be renewed or overhauled where necessary. If journals, etc., show wear, the bearings must be adjusted, using lead wire. All oil cups must be cleaned and covered up. All joints of caps, covers, etc., on working parts must be covered to prevent grit or dirt getting in the journal.

All machinery, valves, etc., must be worked every day.

All repairs, the necessity for which was noted while the engines were running, must be made.

All oil cups and oil ways must be examined and cleaned. All holding down bolts, set screws, etc., must be examined.

All steam and exhaust piping not in use must be kept thoroughly drained.

The boilers should be kept clean. If necessary lay off one at a time while steaming to have it properly scaled and cleaned, after which, if not going into regular use, it should be filled full of fresh water, and a solution of caustic soda should be injected into it to prevent corrosion from taking place. The air cock on top should be tried every few days to see that the boiler is full, the pumps being turned on for the purpose of forcing the air and water through the cock.

All the grate and bearing bars should be removed and cleaned while cleaning the boilers, all scale and dirt should be removed from inside the tubes and the back connections, front connections and furnaces, and, if the boiler is not to be used for some time, the inside surfaces of tubes and back connections of furnaces should be oiled with a mineral oil.

Any leaks around the boilers must be stopped if possible.

If the boilers are likely to be needed at short notice the fires may be laid and the water in the boilers may be kept up to near 212° by using steam from auxiliary boilers, either by injectors to heat the water or to blow steam directly into lowest part of boiler, or by pumps taking hot water from the auxiliary boilers and pumping it into the main boilers.

In putting a boiler out of use, the fires should be allowed to die out, the ash pan doors being kept closed to prevent cold air passing through the tubes, etc. When the fires are out and the temperature of water is lowered sufficiently, the water can be *pumped* out and the boiler then opened; when it should be cleaned at once, while the scale and dirt are soft. The boiler should then be thoroughly examined.

In getting up steam, the fires should be allowed to burn very slowly at first, to allow all parts of the boiler to expand slowly and evenly. Four hours at least should be taken when the water is cold at the start. Less time is needed when the water is already near the boiling point when the fires are started. Artificial circulation should be provided while getting up steam.

All iron or steel surfaces should be kept clean and covered with a good coat of paint.

All pumps, valves and pipes must be examined and kept in good condition. The bilges and double bottoms must be kept clean, dry and well painted, and, if cemented, the cement must be kept in repair.

Question No. 4.—Explain how best to obtain economy in the use of coal, oil, etc. (This will involve such considerations as the number of boilers to be used for a given power, the rate of combustion of coal, the steam pressure and point of cut-off to be used, the economical speed of the ship and the best method of lubrication.)

The question of economy of coal while steaming is one that can only be determined by experiment for each ship.

In general, the most economical speed for a ship is from one-half the maximum speed to one knot above half speed, and, as a general thing, this speed can be obtained under natural draft with one-half boiler power. If that be not boiler power enough, it would be better to add another boiler rather than to use forced draft, as the former method increases the steam room so that the steam will reach the engines in a dry condition, and also as the rate of combustion per sq. ft. of grate surface will be less. It may be necessary to use "assisted draft" in cases where the natural draft is crippled by insufficient hatches, etc.

The rate of coal consumption should be about 10 to 12 lbs. per sq. ft. of grate surface per hour. The steam pressure should be the highest working pressure allowed; the point of cut-off being adjusted to give the speed mentioned above, provided it does not give too high a rate of expansion, thus reducing disproportionally the power of the L. P. cylinder.

When steaming against a current, the most economical speed is one and one-half times the speed of current, provided that this speed is not below one-half the maximum speed of the ship.

The most economical and best method of lubrication is by using wick cups for all journals and wearing surfaces.

If sight-feed cups only be fitted, great care is necessary to prevent a waste of oil when running at cruising speed, as their regulation is not easily effected.

Cylinder oil should be used sparingly. If the cylinder walls are oiled when cleaned, no oil should be necessary for at least twelve hours after starting the engines, and then only a very little should be used.

Question No. 5.—Give a list of parts of steam machinery subject to wear, and state the course to pursue to maintain efficiency, together with a statement of cases where deterioration is certain and cannot be compensated.

All journals and wearing surfaces are subject to wear, the amount depending upon the work done upon them, the lubrication of the parts, and the materials of which they are made.

The shaft and crank-pin bearings are the principal ones subject to wear, and when it becomes excessive the shafting is thrown out of line and the clearance in the bottom of the cylinders is reduced, perhaps to a dangerous point. To overcome the effects of wear, a great many engines are so fitted that the bottom brasses of the crank shaft bearings can be wedged or lined up. Liners can also be fitted back of flat brasses of crank-pin journals, so as to keep the original length of connecting rods. In other engines where the brasses are cylindrical on the outside so that a liner cannot well be fitted, it may be necessary to rebabbitt them.

The different journals of the valve motions being all subject to wear, thus changing the action of the valves and the distribution of the steam in the cylinders, need to be kept in adjustment by means of liners or by lengthening the valve stems.

The piston packing rings may wear, but their elasticity and the pressure of the springs should compensate for any ordinary wear.

The go-ahead wearing surfaces of the thrust block will show wear if not properly proportioned and well lubricated. Adjustment is usually made by screws or wedges and keys.

The crosshead gibs can be adjusted for wear by liners and set bolts.

If any wearing surface is cut or at all rough, it should be carefully trued up and smoothed by using files or scrapers.

The cases where deterioration is certain to occur are in the boilers and in both steam and water piping, reducing their strength by corrosion and erosion, and finally necessitating the reduction of steam pressure and causing loss of efficiency in boilers and breakages in piping.

Wear is also certain in the outboard bearings of the shafts, but this can only be remedied while the vessel is in dock.

Question No. 6.—Give a list of the machine and hand tools that are carried on board a modern war vessel, with a statement of new and repair work that can be performed aboard. (Both the list of tools and of work should be given in a general way, not going much into detail, the object being to see that the candidate knows what work can be done on board and what must be done at a shop on shore.)

On board every modern man-of-war large enough to permit it should be carried a gap lathe, planer or shaper, milling machine, emery wheels, and a drill press and vises, all fitted in the machine shop, a full set of tools being carried for each machine, the sizes of the machines being of course governed by the capacity of the shop.

Portable or electric drills should also be carried.

A full set of boilermaker's, blacksmith's, coppersmith's and carpenter's tools should be carried.

Crucibles to hold from 25 to 100 lbs. of metal should also be furnished, as small castings that can be made on board ship are often needed.

Repair work on board ship is only limited by the facilities therefor. Where hand work only is required and no forging nor heating is needed, repairs should be made on board, if there is room enough to handle the piece. The sizes of the machines carried generally limit the machine work that can be done on board, though sometimes a small lathe may be pieced out to take in a main valve stem or other long light piece.

Question No. 7.—Give a list of the more important stores and spare parts usually carried on board modern war vessels.

The most important stores carried by modern ships are coal; oil; assorted wrenches to fit around all parts of the machinery; packing for all stuffing boxes and joints; tools to perform all repairs; material, such as sheet and bar iron and steel of different sizes; sheet copper and brass; assorted bolts and nuts, both of iron and of bronze; grate bars and firing tools; spare valves for pumps, etc.; spare gauges; assorted lot of piping, pipe fittings and valves; water gauge glasses; spare oil cups of different sizes; spare boiler tubes and tube plugs; white metal for rebabbitting brasses; red and white lead; boiled oil; turpentine and dryers; lead wire for adjusting bearings; fine wire gauze for joints; fire clay; assorted sheet gum; hose; hydrometers; thermometers; indicators; gauge tester; jacks; solder and spelter; acid; assorted zinc wire; steam tube cleaner; charcoal; lye; waste; soap; sal soda.

The spare parts carried depend on the size of vessel (regarding stowage room) and upon the engines. If the ship has duplicate twin-screw engines with crank shafts in interchangeable sections, a spare section of that shaft should be carried; one eccentric; a piston rod and a connecting rod; a couple of valve stems; two spare brasses for crank shaft journals and two for crank pins; one set of cross-head brasses and gibs; a few spare bolts for all parts where of special make, as follower bolts, holding down bolts, etc.; a full set of small brasses and gibs for valve gear and all auxiliary pumps; a couple of eccentric straps; and a set of spare telescopic oil cups.

All spare parts should have been previously fitted in place, so as to make sure that they fit.

Question No. 8.—What inspection and tests should be used in selecting coal, oil, and rubber?

In the inspection of anthracite coal, the amount of slate is estimated by gathering up a pile of it found in the top of a car load of coal. If much be found the coal should be rejected. The coal should be clear of slack, have bright surfaces, no signs of bone (dark lustreless seams through the piece) nor of curly coal (curly coal shows curved or irregular lines).

The best way of testing coal is to burn some of it in a furnace, noting how it burns, whether or not it breaks up in burning, and how much clinker and ash are left.

Bituminous coal should have a fair percentage of lumps, and should not be so dry that the dust flies readily, thereby showing that it has been mined for some time and has consequently lost part of its steam-making qualities. There should be no signs of sulphur in the lumps.

Rubber of good quality will return to its original size after being stretched. If with cloth insertion, the cloth must be first removed. If pure gum be lighted, the rubber will boil and drop, like sealing wax, and will burn, leaving little or no ash; but if it be adulterated with clay and other ingredients, a heavy ash will be left. The interior layers of sheet rubber are generally the poorest in quality and should be the ones tested. The cloth should also be examined to see if it is of fair quality.

For tests of oils, the following printed specifications of the Bureau of Supplies and Accounts give all necessary information:

SPECIFICATIONS ISSUED BY THE BUREAU OF SUPPLIES AND ACCOUNTS, NAVY DEPARTMENT, APRIL, 1899.

OILS.

LINSEED OIL, BOILED.—Must be absolutely pure kettle-boiled oil of the best quality, and the film left after flowing the oil over glass and allowing it to drain in a vertical position must dry entirely free of tackiness in 60 hours at a temperature of 70° F. To be purchased and inspected by weight.

LINSEED OIL, RAW.—Must be absolutely pure, well-settled oil, of the best quality; must be perfectly clear, and not show a loss of over 2 per cent when heated to 212° F., nor show any deposit after being heated to that temperature. The specific gravity must be between 0.932 and 0.937 at 60° F. To be purchased and inspected by weight.

CYLINDER OIL.—Must be a pure, mineral, hydrocarbon oil, with a flash point of at least 550° F.; burning point to be above 600° F.; to be free from tarry or suspended matter, acid, or alkali, and from mixture or adulteration with animal, vegetable, or fish oils, grease, lard, or tallow. Specific gravity to be not below 0.900 nor above 0.906 at a temperature of 60° F. To be purchased and inspected by weight.

A flash point below 550° F., or the presence of any of the above-named adulterations or mixtures, or a specific gravity different from that specified, will be sufficient to cause the rejection of the oil.

Test of Cylinder Oil.

1. *Flashing point.*—Heat a small quantity of the oil in an open vessel, not less than 12° per minute, and apply the test flame every 10°, beginning at 250° F.

2. *Precipitation test for tarry and suspended matter.*—Mix 5 cubic centimeters of oil with 95 cubic centimeters of 88° gasoline, and if there is any precipitation in ten minutes the oil must be rejected. This test is easiest made by putting 5 cubic centimeters of oil in a 100 cubic centimeter graduate, then filling to the mark with gasoline and thoroughly shaking.

3. *Volatility.*—Kept heated to 400° F., in an open vessel, it must not lose more than 5 per cent of its weight in two hours.

4. *To test for acid or alkali.*—It will be sufficient to wash a small quantity of the oil with distilled water, then drain off the water and test it with litmus paper.

LARD OIL.—Must be of the best quality and made from fresh lard. To be purchased and inspected by weight.

Oil will not be accepted which—

I. Contains admixture of any other oil.

II. Contains more acidity than the equivalent of 2 per cent of oleic acid.

III. Shows a cold test above 42° F.

IV. Shows coloration when tested with nitrate of silver, as described below.

V. A half pint of the oil placed in an ordinary hand lamp without a chimney must burn with a clear, bright flame till 90 per cent of the oil has been consumed; the lamp to be placed where it will not be affected by draft or air currents, and the wick not be touched during the trial.

1. *Test of lard oil.*—The cold test of oil is determined as follows: A couple of ounces of oil is put in a 4-ounce sample bottle, and a thermometer placed in it. The oil is then frozen, a freezing mixture of ice and salt being used if necessary. When the oil has become hard, the bottle is removed from the freezing mixture and the frozen oil allowed to soften, being stirred and thoroughly mixed at the same time by means of the thermometer until the mass will run from one end of the bottle to the other. The reading of the thermometer, when this is the case, is regarded as the cold test of the oil.

2. The nitrate of silver test is as follows: Have ready a solution of nitrate of silver in alcohol and ether, made on the following formula:

Nitrate of silver	1 gram.
Alcohol	200 grams.
Ether	40 grams.

After the ingredients are mixed and dissolved allow the solution to stand in the sun or in diffused light until it has become perfectly clear; it is then ready for use, and should be kept in a dim place and tightly corked.

Into a 50-cubic centimeter test tube put 10 cubic centimeters of the oil to be tested (which should have been previously filtered through washed filtered paper) and 5 cubic centimeters of the above solution; shake thoroughly and heat in a vessel of boiling water fifteen minutes, with occasional shaking. Satisfactory oil shows no change of color under this test.

3. For the burning test, an ordinary tin hand lamp to conform to the following description will be used:

Diameter of lamp at base 3-1/8 inches; height of cylindrical portion 2-1/4 inches; height of top of burner from bottom of lamp 2-7/8 inches.

The burner will consist of two conical tubes placed side by side, each 1-1/2 inches in length, 15/64 inch inside diameter at top and 11/32 inch inside diameter at bottom. The wick will consist of a sufficient number of threads of ordinary cotton lamp wicking, in each tube, to make a properly fitting wick for lard oil.

LUBRICATING OIL FOR CUTTING TOOLS.—Must be of the best quality, and pass satisfactorily the following tests, to be made with instruments belonging to the government, in the navy yard:

1. *As a lubricant.*—On an oil-testing machine at least 50,000 foot-pounds of work must be performed per minute per troy grain of oil used. The pressure on the bearing must not be less than 250 pounds per square inch of projected area, and the temperature of the rubbing surfaces at the end of two hours must not exceed 150° F. The surfaces to be a polished steel mandrel running in standard brass bearings.

2. *Specific gravity.*—Must not be less than 0.9000 at a temperature of 60° F. To be purchased and inspected by weight.

3. *Flashing point.*—Must not be below 400° F.

4. *Freedom from gumming.*—Just sufficient oil to cover the bottom thereof will be placed in a shallow dish; this will be heated to about 250° F., and then cooled slowly. When cold, there must be no gummy residue found in the oil or on the vessel.

A common oil cup holding about two ounces will be filled with the oil; two threads of worsted will be used as a wick, and all the oil in the cup must feed through it; the wick not to be touched during the trial. This test to be made at a temperature between 70° and 90° F.

5. *Cold test.*—The oil must not solidify at a temperature of 32° F.

6. *Freedom from acid.*—A small quantity of oil rubbed on polished brass or copper must not turn the surface of the metal green if allowed to stand for twenty-four hours.

SPERM OIL.—Must be pure, winter-strained, bleached sperm oil, free from mixture or adulteration with animal, vegetable, or fish oil, grease, lard, or tallow. To be purchased and inspected by weight.

LUBRICATING OIL FOR EXPANDER CYLINDER OF DENSE AIR ICE MACHINE.—Must be of the best quality, free from adulteration, and pass satisfactorily the following tests, to be made with instruments belonging to the government, in the navy yard.

1. *As a lubricant.*—On an oil-testing machine at least 50,000 foot-pounds of work must be performed per minute per troy grain of oil used. The pressure on the bearing must not be less than 250 pounds per square inch of projected area, and the temperature of the rubbing surfaces at the end of two hours must not exceed 150° F. The surfaces to be a polished steel mandrel running in standard brass bearings.

2. *Specific gravity.*—Must be between 0.8974 and 0.8917 at a temperature of 60° F. To be purchased and inspected by weight.

3. *Flash point.*—Must be above 390° F.

4. *Freedom from gumming.*—Just sufficient oil to cover the bottom will be placed in a shallow dish; this will be heated to about 250° F., then cooled slowly. When cold, there must be no gummy residue found in the oil or on the vessel.

A common oil cup holding about two ounces will be filled with the oil; two threads of worsted will be used as a wick, and all the oil in the cup must feed through it; the wick not to be touched during the trial. This test to be made at a temperature between 70° and 90° F.

5. *Cold test.*—The oil must remain liquid at a temperature of 7° F.

6. *Freedom from acid.*—Must be free from all traces of acid. A small quantity of oil rubbed on polished brass or copper must not turn the surface of the metal green if allowed to stand for twenty-four hours.

WHALE OIL.—Must be best grade of bleached winter-strained oil, free from adulterations with other oils.

1. Tested with litmus paper, it must show no trace of acid.

2. It will begin to become torpid at from 35° to 42° F., and cease to flow at from 17° to 18°F.

3. Specific gravity at 60° F., from 0.9151 to 0.9174. To be purchased and inspected by weight.

4. Oil must be accompanied by a guarantee from the manufacturer that it is pure whale oil.

Inspection and Delivery of Oil.

1. Before acceptance, the oil will be inspected; samples of each lot will be taken at random, the samples well mixed together in a clean vessel, and the sample for test taken from this mixture. Should the mixture be found to contain any impurities or adulterations, the whole delivery of oil it represents will be rejected, and is to be removed by the contractor at his own expense.

2. The quantity delivered to be determined by weight—the number of pounds per gallon to be determined by the specific gravity of the oil at 60° F. multiplied by 8.33 pounds, the weight of a gallon (231 cubic inches) of distilled water at the same temperature.

3. To be delivered in strong, tight, well-made, white-oak casks, hooped with iron, each having a capacity not exceeding 50 gallons;

4. Or, in new shipping cans, to average not less than 2-1/2 pounds each in weight, made of "I. C." bright tin, the black plate properly coated. The capacity of the cans to be not less than 5-3/16 gallons, but not more than 5 gallons of oil to each can to be paid for. The cans to be well made, with a top handle, and to have on top near one corner a 1-1/2-inch closed screw cap, so packed as to prevent leakage when screwed tight. Cans to be packed in wooden cases, two cans to a case, cases to be made of 7/8-inch new pine throughout, dressed on outside, with tight cover, of such size as to take the cans fitting closely. The space between the cans, if any, to be filled by inserting a loose piece of wood, full width and height of can. A strip of wood of proper thickness to be inserted between the cans and cover of case, to protect the screw caps. Cans and cases to be made in the best workmanlike manner.

NOTE.—U. S. Navy Regulations Circular No. 121 requires—

1. Deliveries of oil may be made in lots of not less than 5000 gallons, with the exception that the final delivery may be a less quantity, but the whole quantity must be delivered within the time specified by the contract.

2. Each delivery will be considered a lot by itself; and each lot will be inspected and accepted or rejected, as it passes, or fails to pass, the test required.

3. Upon the rejection of any lot of oil delivered, no second test nor any second delivery in place of the lot rejected will be permitted, but the quantity rejected will at once be purchased in open market for the contractor's account.

GENERAL NOTE.—In making requisitions for oils, the above specifications should be referred to "as per Official Specifications of April, 1899."

Subject No. 3.—Duties of an Engineer on Shore at a Navy Yard or as an Inspector of Machinery building by Contract.

Question No. 1.—Describe a general survey of the machinery of a ship returned for refitting at the end of a cruise, and state what parts would require most careful examination and what work would generally be done to put the machinery in thoroughly good condition.

In making a general survey of a ship that is to be refitted after long service, all parts should be examined, especially the alignment of the shafting and the condition of all its journals and bearings; the alignment, trueness of bore, and the condition of the cylinders, valve seats, or of the bore of the valve chests; condition of pistons and valves; condition and alignment of slides or guides; and of cross-head gibs and journals; the condition of eccentrics and valve motions, and of the holding down bolts of engine.

The boilers should be tested by hydrostatic pressure for leaks, and should then be uncovered and given a hammer test for deterioration of plates, braces, etc. All parts most liable to corrosion by pitting or grooving, such as near water line, and around the feed orifice, where no interior feed pipes are fitted, should be thoroughly inspected. The boiler valves, saddles and holding-down bolts should be carefully examined.

The steam and water piping should be tested by hydrostatic pressure and all valves should be tested for tightness. Worn out piping and valves should be renewed.

The condensers should be tested for tightness and examined for cleanliness. All auxiliary machinery should be thoroughly overhauled.

As a general thing, besides the work indicated above, new brasses should be fitted or the old ones rebabbitted, new packing rings and springs should be put in pistons, and the pistons and followers should be faced off.

All outboard valves, the screws, shafts, and the exterior shaft bearings and fastenings, should be examined and put in perfect order.

Question No. 2.—State how estimates of time and cost are made in case of repair work. (The board will give a statement of the character and amount of repairs required.)

Estimates of time and cost of repair work are made by seeing exactly what repairs are needed, what new work is necessary and what old work must be removed.

The time is estimated by knowing what one man can do of each class of work necessary in one day, and by estimating how many men can work to advantage on the job. The facilities for carrying on this work, as space to work in, distance from shop, etc., must be considered.

The cost is calculated from the number of men employed, their pay per day and the number of days' work necessary, this giving the cost of labor, which cost is combined with that of material required, as estimated or calculated from the weight needed and its cost per pound.

On boards of survey each item is separately estimated for as follows:

New pair of crank shaft brasses.

Time required ....working days.
Cost of labor ....$
Cost of material ....$

Total cost ....$

Question No. 3.—Name the tools and appliances generally fitted in a modern plant for the building and repair of marine machinery of large size, giving some idea of the size of the various tools, cranes, etc.

A modern plan for building and repairing marine machinery should have in the *machine shop* planers of various sizes up to 15-foot gap and 20-foot stroke; lathes of various sizes up to 5-foot swing and to take in a 50-foot shaft; gap lathe to take a piece of machinery 18 feet in diameter; screw-cutting lathes of various sizes; boring mills, vertical and horizontal, to bore out cylinders 110 inches in diameter and 8 feet in length; slotting machines of various sizes, the largest to have a gap of 6 feet and able to take a cut of 1/8 inch by 1 inch; shaping machines, the largest being able to cut 1/8 inch by 3/4 inch; radial drill presses up to one having a radius of 8 feet and for drilling up to 5-inch holes; bolt and screw machines; gear-cutting machines; pipe-cutting machines and threading machines; milling machines; emery grinding machine to take in all shaftings, etc., for any vessel; and emery buffing machines. Portable drills are also used, having capacity up to 1-1/2-inch diameter holes.

Vise benches should be fitted all round the walls. Large tools should be grouped in a separate part of shop from the small ones.

There should be provided overhead power or electrical travelling cranes of 30 tons capacity, able to carry work to any part of the shop, and also car tracks for moving parts of machinery to different parts of the shop on small cars.

The *erecting shop* should have good erecting bed plates on a solid foundation, an overhead crane of 25 tons capacity, vise benches around walls, and one or two small lathes, planers and drill presses.

The *boiler shop* should have an hydraulic flanging machine capable of flanging 2-inch steel plate; an hydraulic riveter capable of driving 2-inch steel rivets; shears capable of cutting 2-inch plate; steel angle iron shears; punches capable of punching a 2-inch hole through a 2-inch plate of steel; plate planers capable of taking a plate 30 feet long and planing the edges of 2-inch plates, cutting 1 inch by 1/8 inch; flange fires capable of heating a plate 12 feet in length and 6 feet wide; drill presses with six independent and movable drill heads for drilling boiler shells, etc.; radial drills with working radius of 9 feet for drilling tube sheets; vertical and horizontal rolls capable of bending cold steel plate 2 inches thick and 10 feet wide; portable drills, rivet forges, etc., and blowers for forges; and electrical drills for use in various parts of boilers not easily accessible for other power drills.

There should be an overhead travelling crane capable of lifting and travelling with a weight of 90 tons, and also an annealing furnace, capable of taking a plate 18 feet wide by 30 feet long, with straightening bed plates of same size.

The *foundry* should contain cupola furnaces having a total capacity of 20 tons, and air furnaces with 10 tons capacity, besides crucible ovens, etc., and drying ovens of 20 feet diameter. There should be an overhead travelling crane of 30 tons capacity able to reach any part of the shop.

There should be a *forge shop,* containing heating furnaces and steam hammers or hydraulic presses capable of forging down an ingot of steel 50-inch by 50-inch section for shaft work; also smaller hammers or presses and small forges for hand work.

The *coppersmith shop* should have rolls to take in sheets 10 feet long and to roll 5 inches in diameter; small hydraulic presses for bending pipes; shears; fires for brazing and for annealing; baths for cleaning piping and for tinning the same; and testing machines for piping and condenser tubes.

The *pattern shop* should be fitted with various sizes of wood planers; lathes; saws, both circular and band; mortising machines; benches, etc.

Question No. 4.—State the amount of work that can reasonably be expected during a working day of eight hours on any one of the following kinds of work:—(a) turning plain shafting; (b) boring large *engine cylinder; (c) plain work in an hydraulic flanging machine (thickness of plate to be given); (d) riveting in an hydraulic riveter (thickness of plates and diameter of rivets to be given); (e) drilling rivet holes in boiler shells (thickness of plates, diameter of holes, and kind of drilling machine to be given); (f) planing valve seats on large cylinders; (g) drilling and tapping holes in condenser-tube sheets.*

(*a*). *Turning plain shafting.*—The new lathe in the New York yard will take a cut 1-1/4 inches deep, with a 1/8-inch feed and a speed of 12 feet per minute for the cutting tool, which equals 10,800 cu. ins. per diem.

The old lathe will cut 3/4 inch deep, with a feed of 1/32 inch and a speed of tool of 12 feet per min., which gives 1620 cu. ins. per diem.

The above statements apply only to roughing cuts; a second cut would be 1/8 inch deep, with feed of 1/32 inch, at 15 feet per min., which gives 340 cu. ins. per diem.

For the finishing cut, use a 1/32-inch feed, with a 1/8-inch feed and a tool speed of 15 feet per min., and we get 340 cu. ins. per diem.

(*b*). *Boring large cylinder,* in New York yard. At least three tools should be used on the boring head.

$$\text{Roughing out}\left\{\begin{array}{l}\text{1st tool 1/4-in. cut}\\ \text{2nd tool 1/8-in. cut}\\ \text{3rd tool 1/8-in. cut}\end{array}\right\} = \begin{array}{l}\text{1/2-in. cut with 1/32-in.}\\ \text{feed; at least 12 ft. per}\\ \text{min. speed of tools,}\\ \text{which gives 1080 cu. ins.}\\ \text{per diem.}\end{array}$$

The finishing cut should be taken without stopping, and with a 1/32-inch feed, 3/8-inch cut, and a speed of 10 feet per min. = 675 cu. ins. per diem.

With a good boring mill, a 60-inch diameter cylinder should be bored out 16 inches in length in eight hours for a roughing cut, and about 32 inches for a finishing cut.

For above two questions, the kind of material makes a vast difference, as with some hard steel or cast iron only very light cuts can be taken without breaking the tools. However, the above will be about a fair average for ordinary material.

(*c*). *The amount of plain work in an hydraulic flanging machine* depends upon the number of flange fires used in heating the plates, as the machine, (if powerful enough) will flange a thick plate just about as quickly as a thin one, and can flange and flatten about 6 or 7 feet at a heat, taking about 5 or 6 minutes to do it, after which the plate is too cool to work.

If the fire be properly maintained, a 3/4-inch plate can be heated in 30 minutes, and it would therefore take about four flange fires to keep the flanging machine at work. A thicker plate than 3/4 inch will require more time and therefore more fires to keep the machine working.

If everything be well arranged the plate should be put in the machine, have about 6 feet of flanging done, and the plate removed in 10 minutes, or say 50 feet per hour for straight work.

(*d*). *An hydraulic riveter* is said to have driven 1935 7/8-inch rivets in 8-1/2 hours—this, of course, is exceptional and was for perfectly straight work.

In building boilers for the Cincinnati the hydraulic riveter drove 219 1-1/4-inch rivets in one hour and forty minutes, or at the rate of 1051 rivets for 8 hours. This was on a straight circumferential seam previously tacked down.

The amount of ordinary work that should be done in 8 hours is about 700 or 800 rivets. The size of the rivets has little to do with the number, provided the machine be powerful enough to do the work, otherwise two or three strokes may be necessary on each rivet.

(*e*). A Dallet drill used in drilling shells of boilers for the Cincinnati drilled a 1-5/16-inch hole through 2-3/8 inches of mild steel in 7-2/3 minutes; and the time used in shifting the drill to the next hole was 2/3 of a minute; say 9 minutes per hole, which is at the rate of 53 holes per diem.

(*f*). In planing the valve seats of a large cylinder, lighter cuts would have to be taken than on ordinary straight work (where about 6 feet square would be finished per diem) in order not to run the risk of breaking the edges of the bridges between ports; say about 4 feet square, or from 16 square feet to 20 square feet of surface per diem, including roughing and finishing cuts, but not the setting of the cylinder.

(*g*). At the Columbian Iron Works the drilling is done by machine and the tapping out by hand, the amount of work done being 60 holes per diem in a 1-inch thick condenser-tube plate. At the South Brooklyn Steam Engine Works, where a specialty is made of building condensers, they core out the holes when the plate is cast, then ream and tap 500 holes per diem.

Question No. 5.—Give a general idea of the method of conducting the evaporative test of a steam boiler, stating the special precautions necessary to ensure accurate results.

The following blank forms of the Bureau of Steam Engineering (Nos. 104—1-2-3-4-5-6) give all the information necessary in regard to the evaporative tests of steam boilers.

S. E. Form No. 104-1.

DATA AND RESULTS OF EVAPORATIVE TEST.

Made by ....
of ....**boiler, at** ....
to determine ....
....
....

Principal conditions governing test..................................
....
....
....

S. E. Form No. 104-2.

DESCRIPTION AND DIMENSIONS OF BOILER AND APPURTENANCES.

Type of boiler ....
Diameter of shell, ...; top drum, ...; bottom drum, ...
Length of shell, ...; top drum, ...; bottom drum, ...
Tubes, number,....; diameter, outside,....; length,....; thickness,...
Furnace, kind of, ...
Furnace, length,...............; width,...........; height,...........
Grate surface, length............; width,...........; area,...........
Heating surface, area,................; ratio to grate,................
Per cent water heating surface,..; per cent superheating surface,..
Grate bars, kind, ...
Grate bars, width of air spaces,....; ratio of grate to air space,....
Smoke pipe, area,.........; height,........; ratio to grate,..........
Water space,.....................; steam space,.....................
Weight of boiler and all fittings except uptakes and smoke pipe:
Without water, ...
Water ....
Total with water ....
Total weight per square foot of grate surface,.......................
Total weight per square foot of heating surface,.....................

Blower engines, kind,........; Dimensions of cylinders, x x
Blower fan, kind,.................; diameter,........; width,........

Area of blower inlet,....................; outlet,...................
Feed heater, kind,..
Feed heater, area of surface,...
Economizer, kind, ...
Area of surface,...
Air heater, kind, ...
Area of surface,...
Feed pumps, kind,...........; dimensions of cylinders, x x
Other boiler appurtenances,...

S. E. Form No. 104-3.

DESCRIPTION OF APPARATUS.

a Method of weighing water...
....
....
....
....

b Method of weighing fuel..
....
....
....
....

c Method of determining the amount of moisture in steam.
Kind of calorimeter used...
Distance of calorimeter from boiler.....................................
Size, shape, and description of sampling nozzle...................
....
....
....
....

d Method of taking temperature of and of sampling flue gases.....
....
....
....

e Condition of boiler before and after test.............................
....
....
....
....

S. E. Form No. 104-4.

NUMBER OF TEST................. ....
1. Date of test..................................... ....
2. Duration of test.......................hrs. ....

3. Kind of fuel.................................. ....
4. Kind of start................................. ....
5. State of weather.............................. ....

AVERAGE PRESSURES.

6. Barometer ....ins. ....
7. Steam pressure by gauge.................lbs. ....
8. Force of draft at base of pipe..ins. of water. ....
9. Force of draft in furnace...........do...... ....
10. Force of draft in ash pit.............do...... ....
11. Revolutions of blower ....

AVERAGE TEMPERATURES.

12. External air ....degrees F. ....
13. Fire room ....do.... ....
14. Steam ....do.... ....
15. Feed water entering heater............do.... ....
16. Feed water entering economizer.......do.... ....
17. Feed water entering boiler............do.... ....
18. Air entering ash pit..................do.... ....
19. Escaping gases from boiler............do.... ....
20. Escaping gases from economizer......do.... ....

FUEL.

21. Kind of ....
22. Weight of wood used in lighting fires....lbs. ....
23. Weight of coal as fired*.................lbs. ....
24. Moisture in coal...................per cent. ....
25. Weight of dry coal consumed............lbs. ....
26. Weight of ash and refuse................lbs. ....
27. Weight of combustible consumed........lbs. ....
28. Per cent of refuse in dry coal............... ....

FUEL PER HOUR.

29. Coal consumed per hour.................lbs. ....
30. Dry coal consumed per hour.............lbs. ....
31. Combustible consumed per hour.........lbs. ....
32. Coal consumed per hour per sq. ft. G. S...lbs. ....
33. Dry coal consumed per hour per sq. ft. G. S. ....lbs. ....
34. Combustible consumed per hour per sq. ft. G. S. ....lbs. ....

S. E. Form No. 104-5.

NUMBER OF TEST..

35. Coal per hour per sq. ft. H. S............lbs. ....
36. Dry coal per hour per sq. ft. H. S........lbs. ....
37. Combustible per hour per sq. ft. H. S....lbs. ....

---

* Including equivalent of wood used in lighting fires.

QUALITY OF STEAM.

38. Per cent of moisture in steam.............. ....
39. Degrees of superheating.................... ....
40. Quality of steam (dry steam = 100).......... ....

WATER.

41. Total weight of water fed to boiler*....lbs. ....
42. Water actually evaporated, corrected for quality of steam (40 by 41)...........lbs. ....
43. Factor of evaporation...................... ....
44. Equivalent water evaporated into dry steam from and at 212° (42 by 43).....lbs. ....

WATER PER HOUR.

45. Water evaporated per hour, corrected for quality of steam.....................lbs. ....
46. Equivalent evaporation from and at 212°..... ....
47. Equivalent evaporation from and at 212° per sq. ft. G. S.....................lbs. ....
48. Same per sq. ft. of heating surface......lbs. ....

ECONOMIC RESULTS.

49. Water apparently evaporated under actual conditions per lb. of coal as fired (41 ÷ 23) ....lbs. ....
50. Apparent equivalent evaporation from and at 212° per lb. of coal (including moisture) 44 ÷ 23 ....lbs. ....
51. Equivalent evaporation from and at 212° per lb. of dry coal (44 ÷ 25)..........lbs. ....
52. Equivalent evaporation from and at 212° per lb. of combustible (44 ÷ 27).......lbs. ....

EFFICIENCY.

53. Efficiency of boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible. (*See* Sheet No. 6)................. ....
54. Efficiency of boiler, including grate; heat absorbed by the boiler per lb. of dry coal, divided by the heat value of one lb. of dry coal. (*See* Sheet No. 6)......... ....

REMARKS AND OBSERVATIONS.

55. Principal data taken every.................. ....
56. Percentage of smoke as observed........... ....

---

* Corrected for inequality of water level and steam pressure at beginning and end of test.

57. Method of observing same.................. ....
58. Kind of firing (spreading, alternate, or coking)............. ....
59. Average thickness of fires.................. ....
60. Average intervals between firings for each furnace during time fires were in normal condition ....
61. Average interval between times of breaking up ....
62. Efficiency of firemen; expert, average, or poor ....

S. E. Form No. 104-6.

FUEL AND GAS ANALYSES.

PROXIMATE ANALYSIS OF FUEL.

	Coal. Per cent.	Combustible Per cent.
Fixed carbon	....	....
Volatile matter	....	....
Moisture	....	....
Ash	....	....
Total	100 00	100 00
Sulphur separately determined	....	....

ULTIMATE ANALYSIS OF DRY FUEL.

	Coal. Per cent.	Combustible Per cent.
Carbon (C)	....	....
Hydrogen (H)	....	....
Oxygen (O)	....	....
Nitrogen (N)	....	....
Sulphur (S)	....	....
Ash	....	....
	100 00	100 00
Moisture in sample of fuel as received	....	....

ANALYSIS OF ASH AND REFUSE.

	Per cent.
Carbon	....
Earthy matter	....

CALORIFIC VALUE OF FUEL.

Kind of calorimeter used,..
Calorific value by calorimeter, per pound of dry coal,........B. T. U.
Calorific value by calorimeter, per pound of combustible,.... do.
Calorific value by analysis, per pound of dry coal,............ do.
Calorific value by analysis, per pound of combustible,....... do.

ANALYSIS OF DRY GASES.

	Per cent.
Carbon dioxide (CO_2)	....
Oxygen (O)	....
Carbon monoxide (CO)	....
Hydrogen and hydrocarbons	....
Nitrogen (N) (by difference)	....
	100 00

Question No. 6.—State the preparations that would be made for a full power trial of the machinery of a modern war vessel, including a list of stores and instruments that should be furnished.

In preparing for a full power trial of the machinery of a vessel, the boilers should be examined and seen to be perfectly clean, the valves and gauges all right, the safety valve gear working properly, the tubes, connections and furnaces clean, the grate bars in good order, the boiler plates properly put on and the boilers filled with fresh water up to the steaming level. The blowers, and, in case of closed ash pit forced draft, the air ducts, must be in perfect order, and, for closed fire rooms, the air locks and doors must be all right, and it must be determined by actual test that the required air pressure can be maintained.

In the engines, the following parts should be examined and put in best condition; viz.: the cylinders, pistons and packing; the cylinder relief and drain valves; the main valves; the packing in all stuffing boxes; the oil cups, pipes and oil ways; the water pipes to journals and bearings clear and clean; the condensers tight and clean; the air, circulating and feed pumps and all other auxiliary machinery in proper condition.

If steam be on the auxiliary boiler, all pumps, etc., should be tested. See that all bonnets, etc., are in place, and that the joints are properly made. See that all brasses are properly adjusted, setting them up by using lead wire.

There should be some spare parts of small pieces of machinery on board in case of any mishap, which might thus be readily remedied without returning to port; also some of the usual stores carried at sea. A complete set of wrenches should be placed where they can be readily found.

Care should be taken that the coal and oil are of the best quality.

The coal should be carefully weighed into the separate bunkers that are most accessible from the fire rooms, and should be kept there for the actual trial, so that the total amount used may be readily determined. Also see that the coal to be used on the trial is stowed so that, if possible, only one bunker need be opened to each fire room during the trial.

The stores and tools likely to be needed in the fire rooms should be placed in each fire room; the lubricating and cylinder oil should be put in cans distinctly marked, so that no mistake can be made in their use.

All indicators and motions should be put in order, and canvas shields should be rigged to protect them from water.

The engineers should have their stations and duties clearly mapped out beforehand, and should have blanks ready for recording data.

The machinists, firemen, etc., should be properly stationed and well drilled in their duties before the trial takes place. A man should be stationed at every important journal and should not be allowed to leave it during the trial.

The following instruments should be provided for use on the trial:

Indicators and fittings; speed indicators, large and for pocket; a Weaver speed indicator and fittings; air pressure gauges and connections; anemometers; aneroid barometers; thermometers, high grade and ordinary; tanks or meter for measuring feed water.

Question No. 7.—Give a general idea of the work to be done in "laying up" the machinery of a vessel that is to be put in ordinary.

In laying up the machinery of a vessel that is to be put in ordinary, the bonnets and covers should be taken off the machinery, main and auxiliary; all parts should be cleaned; the packing in the stuffing boxes around the machinery should be removed; all journals and wearing surfaces should be well cleaned and oiled, and then the oil cups or oil holes and joints of brasses should be covered so that no dirt or grit can get into the journal.

The bright iron or steel work (excepting wearing surfaces) should be given a good coat of paint.

All pipes should be thoroughly drained, and the packing should be removed from stuffing-box glands, except in the case of outboard valves.

The boilers should be thoroughly scaled and cleaned inside and out, then thoroughly dried inside by putting pans of burning charcoal in the lowest parts of the interiors of the boilers, letting the air escape through the highest openings, also by building light fires in the furnace flues. When the boilers are completely dry, pans of anhydrous lime should be placed in the boilers and all plates should be put on, to prevent any damp air from entering. The connections and furnace flues should be painted, and the interior of the fire tubes should be given a thorough coat of heavy mineral oil, first seeing that the oil is free from acid.

The boilers should be inspected occasionally and if the lime becomes air slacked it should either be renewed by heating or replaced by new lime.

The working parts of the main and auxiliary machinery should be moved twice a week and a lookout kept for any appearance of corrosion.

Question No. 8.—Being assigned to duty as inspector of machinery, tell what special points should be looked after in the inspection of any two of the following:

(*a*). Cylinders;
(*b*). Condensers;
(*c*). Boilers;
(*d*). Shafting;
(*e*). Piston and connecting rods and valve stems;
(*f*). Pistons and valves;
(*g*). Bed plates;
(*h*). Propellers;
(*i*). Boiler and condenser tubes;
(*j*). Brass casting generally.

(*k*). In addition to the two questions specified under this head, the candidate will be furnished with a blue print of some part of the machinery of a naval vessel, and will be required to write therefrom such a specification of the same as should be drawn to accompany a contract for such a part.

An inspector of machinery should pay special regard to the following points while new machinery is being connected:

(*a*). *Cylinders.*—The metal must be a fine close-grained iron, free from blow holes and spongy metal, free from cracks, and not too hard to permit a true finishing cut to be taken, which cut should leave a perfectly clean surface. In machining, see that the proper dimensions, etc., are followed; that all interior parts that are not machined but which come in contact with the steam are properly pickled and cleaned, to get rid of all sand; that no lumps are left on the inner surfaces of the heads to diminish the proper clearance; and that all core plugs and chaplets are perfectly tight.

(*b*). *Condensers.*—See that the metal of the shell and tube sheets is not porous nor spongy; that the joints are properly made in bolting or riveting parts together; that the tubes are properly packed and secured from crawling; and that the tubes have been properly tested. After the condenser is completed, a hydrostatic pressure of 30 pounds per gauge should be first applied to parts in connection with the inside of the tubes or the pressure side, and, after taking off the bonnets in the heads, the like pressure should be applied on the steam side of the tubes.

(*c*). *Boilers.*—The plates, etc., should be tested according to recent specifications. Before being used they should be pickled in one part muriatic acid to 17 parts of water and all mill scale removed, after which the acid should be thoroughly washed off with fresh or lime water. The plates should planed to size, not sheared; plates should be rolled before the holes are drilled, and punching should not be allowed; the joints of plates, straps, and of the different courses should be carefully fitted before the rivet holes are drilled.

After the holes are drilled, all parts should be taken apart to allow the burrs to be cleaned off around the holes, and when that is done they should be put together again so that the holes will come fair.

In riveting, the rivets should be well driven, without cracking the heads, the seam being riveted, being first tacked together at different points before driving rest of rivets.

In flanging, the plates should not be heated too much, nor should they be worked when too cool or near a black heat.

See that no cracks are developed in the flanged parts. When all flanging is done and the sheet is pretty well fitted to place, it should be annealed and then straightened and allowed to cool slowly, after which it should not be worked, except perhaps for some very slight fitting.

The use of dutchmen in fitting of sheets should never be permitted.

All seams and rivets should be caulked from inside the boiler where possible. Front and back tube sheets should be placed parallel to each other. All holes for screw stays from the boiler shell should be drilled after the furnaces are in place; others can be carefully laid out and drilled a little smaller in diameter than when finished, and can be reamed to full size and tapped afterwards.

(*d*). *Shafting.*—The material is nowadays usually steel, and for the tests made to determine the quality thereof see recent specifications.

While the machine work is being done, care must be taken to see that no defects in the material are developed and then covered up by peaning or other methods; that all parts are machined to the required dimensions, especially if it be a built-up crank shaft, where the pins and parts of the shafts fitting into the crank webs must be just large enough to allow the webs to be shrunk tightly on, but not large enough to cause too much stress on the webs when cooling—about 1/100 inch being the usual practice. The axes of the pins and shaft must be exactly parallel to one another, and all journals and pins should be trued by an emery grinder.

(*e*). *Piston and connecting rods and valve stems.*—These are usually forged of steel (for requirements of material see recent specification). While being machined, care must be taken to see that no defects are developed and then covered up.

The piston rods and valve stems must be turned and made as true as possible, and must then be polished. They must be machined to the size given by the drawing.

(*f*). *Pistons and valves.*—The pistons are often made of cast steel, and the valves of cast iron, as steel castings are very apt to contain more or less sand and grit that cannot be machined out of the piece.

The castings, if of steel, should be inspected according to the latest specifications.

While being machined, a lookout must be kept for the development of shrinkage cracks, blow holes, etc., which are very apt to be found in all steel castings. It is always a question whether, if another cut were taken, a large blow hole might not be exposed, so it is well to try a hammer test after the machining is finished, except of course on working surfaces.

If the pistons and valves be of cast iron, the material should be of a tough nature, but not very hard, especially for the valves.

The castings should be free from shrinkage cracks and blow holes, and should be good clean castings.

(*g*). *Bed plates.*—If the bed plates be of cast steel, the remarks in "*f*" on pistons apply. If of cast iron, good tough metal (like old guns or machinery scrap) should be used and the castings should be inspected for cracks, blow holes, sponginess, etc.

(*h*). *Propellers.*—The propellers are generally built up, that is the hubs and blades are cast separately, and, for naval vessels, are made of composition. The usual metal used now in our navy is manganese bronze. A mixture of 50 copper, 45 zinc and 5 ferro-manganese gives a very good hard metal. The blades should be made of a tough metal so that they will bend rather than break.

In turning up the hubs, center lines should be cut around the center and also struck in parallel to the axis, through the centers of the seatings for the blades. The hubs must be accurately bored for the shaft, and the key-ways must be cut. The seatings for the blades must be accurately turned. *There should be no flaws in either hub or blades.*

In regard to the blades, they should be properly secured at the proper pitch, the edges sharpened, and all the surfaces, front and back, smoothed and polished.

(*i*). *Boiler and condenser tubes.*—For the material and test of steel boiler tubes see recent specifications. The tests of iron boiler tubes are about the same. All steel or iron tubes should be pickled in a bath of one part muriatic acid to 17 of water, in order to get rid of all mill scale that is rolled in on the surfaces.

For condenser tubes, each tube should be tested to 500 pounds pressure internally, and, if tinned, the coating of tin must be continuous throughout the length of the tube. A piece of the sample tubes chosen should be flattened out after being laid open in a sheet and then bent to see that the metal is fairly tough and not brittle.

(*j*). *Brass castings generally.*—Should be made of navy bronze 88 C—10 Z—2 T. If the casting requires strength, when old scrap is used it should be toned up by the use of new copper.

If the casting is for a bearing and a hard metal is required, 80 C and 20 T gives a good metal that will not show wear easily.

A lookout should be kept that the castings do not have any shrinkage cracks or blow holes and are not spongy.

(*k*). *Writing specifications.*—The drawings (marked ———) of the parts for which the specifications are drawn, should be incorporated and made part of the specifications, which saves stating all dimensions except the principal ones; the kind and quality of material must be specified and the tests to which it should be subjected. Also it should be stated that all workmanship must be of the best quality and how parts are to be fitted.

Read the specifications for any of the new ships in order to cultivate style.

Subject No. 4.—Practical Work.

Question No. 1. Describe the method of moulding any large piece of machinery in loam, such as a cylinder, propeller, condenser, etc., from a pattern.

For moulding a cylinder in loam from a pattern, see an article in the Journal of the American Society of Naval Engineers, Vol. IV, No. 3, which describes the process, excepting that a "*dummy*" may be swept up, instead of having a pattern made for the cylindrical part.

If we take the case of a propeller blade, a foundation plate is made of proper dimensions, covered with a layer of bricks and mud, then a rough outline of the face of the blade is built of bricks, filled in between with cinders and mud. When the surface of the bricks corresponds nearly to the surface of the blade, a layer of loam 1-inch thick is put on, the blade pattern is oiled, seated and rubbed down into the loam, and then the brick work is built up around the palm, a layer of loam being applied to the pattern, and the bricks being built up against the loam.

The parting surfaces for the cope are next smoothed off, parting sand is applied, the cope is fitted in place, a layer of loam is applied to the top of the blade, and the bricks are seated in the loam and wedged tight in the cope. The cope covers the top of the palm of the blade, but allows for drawbacks fitted for cores, for recesses for bolts, and for a recess to lighten the interior of the palm. After the cope and drawbacks are finished, they are removed, their surfaces are smoothed and black washed, as is also done to the mould after the blade pattern is removed.

All parts are then put in the oven and dried, and are then put into the pit. The sand is rammed in around the mould, and the pouring basin, and runners and gates to the upper edge of the blade and palm are made. The mould is then ready for the metal.

The following description of moulding in loam and casting the cylinders for the cruisers Cincinnati and Raleigh at the New York navy yard is the one referred to above, and is by Commander Geo. H. Kearny, U. S. N. It is here reprinted by the courtesy of the American Society of Naval Engineers.

METHOD OF MOULDING IN LOAM AND CASTING THE CYLINDERS FOR THE CRUISERS CINCINNATI AND RALEIGH AT THE NAVY YARD, NEW YORK.

BY COMMANDER GEO. H. KEARNY, U. S. N.

The cylinders and steam chests are in one casting; the cylinders are unjacketed except on the lower or solid head and only the H. P. cylinder has a wearing liner. All the steam chests have separate cast-iron wearing liners, which were cast with the ports in them.

The following description refers to one of the L. P. cylinders:

From the dimensions given on the drawings a foundation or bottom plate was cast in open sand, of such size as to cover the projected area of the cylinder, steam chest, etc., and to allow for an eight or twelve-inch wall around them.

This plate has lugs and staples by which to bind the mould together and to lift it, and openings through the plate to allow for venting and securing the main cores.

It was cast three inches thick to give sufficient strength and rigidity, as it had to support the whole weight of the mould.

The foundation plate was put in place and leveled, then the iron spindle, about three inches in diameter was placed in position, the foot fitting into a socket bolted to the plate, and the top secured by an arm and braces from the foundry wall.

The vertical position of the spindle was verified by a plumb line and then an arm or "wing" was bolted to the spindle for the purpose of carrying the different "sweeps."

The foundation plate was covered with a layer of brick, on top of which was spread about one-half inch of loam, and a bearing swept up for a guide for the outer part of the mould, and for the lifting ring to rest on.

Center lines, at right angles, were laid out on this seating and the ends transferred to the plate by means of the gauge stick and a plumb line and there marked with a chisel for use in case of the lines becoming effaced in the seating.

Seatings to carry the steam chests were next laid out, their position being determined by means of the center lines and the "gauge stick." This gauge stick is notched in the center so as to allow its center to coincide with that of the spindle, from which point distances are measured, and on it were laid off with the shrinkage rule the different dimensions required.

Horizontal pipes were laid at the bottom of the steam chest seatings, to serve as vents, and the seatings were built up with bricks to the proper height and covered with loam. The bricks were laid with fine cinders between them to give a chance for the gases to escape while pouring the metal.

The flange sweep was next attached to the "wing" and the main flange of the cylinder swept up to size, as given by the gauge stick, with floor sand mixed to a consistency of mud, having "spauls" or chippings of brick mixed in to harden the mass, and then swept up with "slurry" or fine loam sand made liquid and run through a 1/8-inch mesh sieve.

A "dummy" was next built and swept up, corresponding to the circular part of the outer surface of the cylinder, extending from the flange to the top of the jacketed head, as shown in Fig. 1, which also shows the valve-chest seatings, and the foundation and lifting plates.

The "dummy" was built hollow, with one course of brick and a light plate placed near the top to carry bricks and loam, which is swept up to correspond with the outer surface of the solid head. This top plate was slotted radially, to allow it to pass the spindle, and was small enough to allow its edge to be covered with mud to give it a surface.

The dummy was faced with mud, as the bricks absorb the moisture quickly, causing it to harden, and then smoothed over with fine "slurry."

The dummy having been completed, the center lines were transferred to it by means of the gauge stick and plumb line.

Great care was taken to have the dummy the right size, as all the patterns for steam chests, brackets, cylinder feet, ribs, etc., were set up to it.

A "lifting plate" or ring was next cast in open sand, of suitable shape and size to enclose the dummy and to carry all projecting parts of the steam chests, etc. This plate has lugs and staples to allow of its being lifted and for binding the parts of the mould together.

The lifting ring was placed on the seating previously swept up for it, and the lower part of the pattern for the steam chest was placed in position on the valve-chest seatings, and the loam and brick work built up to it, as shown in Fig. 2; after which the patterns for the rest of the steam chests, nozzles, exhaust passages, ribs, cylinder feet, brackets, etc., were laid up to the dummy, their position being determined by means of the center line on the dummy; thus was produced an exact shape or pattern of the outer surface of the whole cylinder.

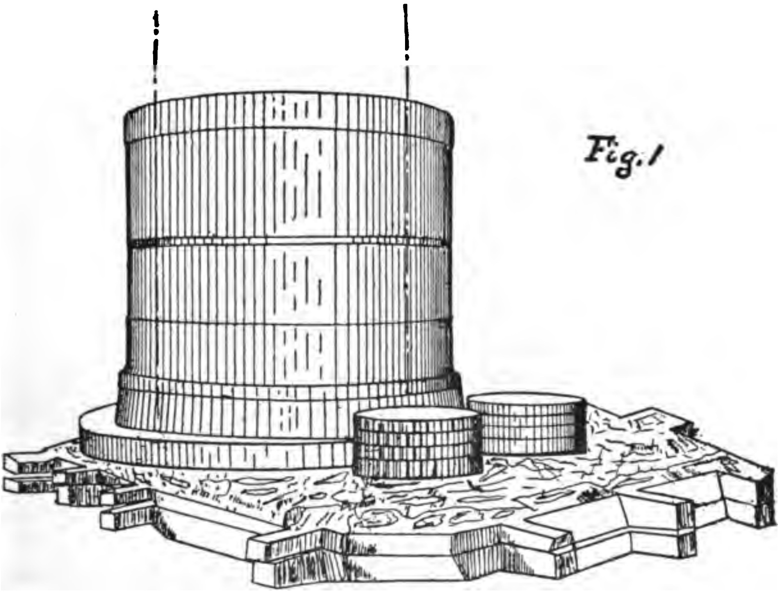


Fig. 1

The surfaces of the dummy and of the wooden patterns were then oiled to prevent the loam from sticking fast to them, and the work of building up the mould proper was begun.

The loam used was a mixture of two parts of coarse moulding sand to one of coarse fire sand, with one-tenth part, by measure, of dry horse manure, the whole being thoroughly mixed together and then passed through a quarter-inch mesh sieve, after which it is mixed with a thick clay water to the consistency of mortar. The manure is used to make the loam porous.

A facing of about one-half inch of this loam was laid on the dummy and patterns, and the bricks laid up to it; the bricks were bedded in mud made of the ordinary floor sand; the brick work was generally eight inches thick, except where necessary to support overhanging parts, when the thickness was increased accordingly. All joints and interstices in the brick work were filled with fine cinders, and at narrow points and corners straw was laid, the object of thus making the mould porous being to allow the ready escape of the gases generated when the metal is cast, so that the surface of the mould will not buckle or "scab," and to assist in thoroughly drying the mould while in the oven.

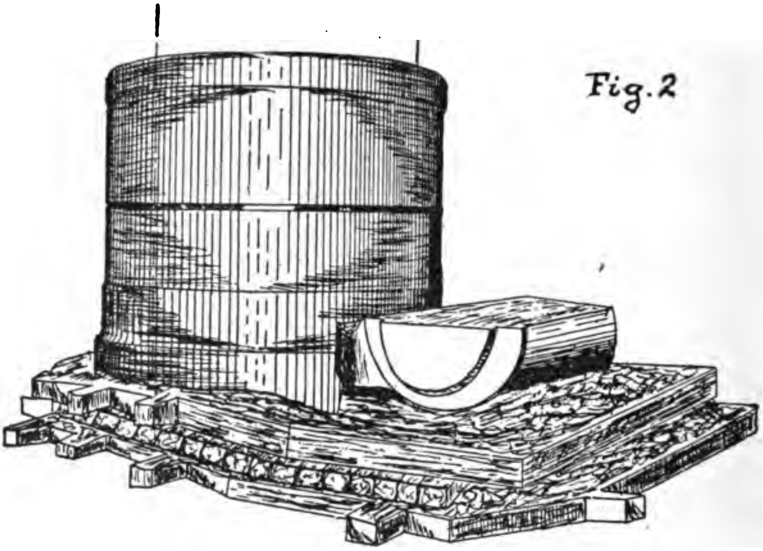


Fig. 2

Where there were any narrow or weak points in the mould they were strengthened by "gaggers" or "anchors" made by bending 3/8-inch or 1/4-inch iron rods to the required shape and size, and securing them in the brick work.

In building up this mould it was necessary to divide it at parts (such as the steam chests) into different sections or "drawbacks," to allow of the patterns being withdrawn and the cores being placed in position. The "drawbacks" were built up on plates cast in open sand to the proper shape, and having a similar plate laid one course of bricks from the top of the "drawbacks," the two plates being secured together when in position by means of hook bolts through staples, so as to form one solid mass.

The seatings for the "drawbacks" were made by covering the brick work with loam and smoothing it, and when this was dry "slurry" was laid on and slicked smooth, and when dry was oiled and parting sand sprinkled over it. On this seating was laid about an inch of loam, in which was bedded the "drawback" plate, having prickers on the under side as well as on top, the plate having been clay washed to make the loam adhere to it.

On this lower plate the loam and brick work for the "drawback" was built up.

These "drawback" plates were laid at a level with stiffening plates in the adjoining parts of the mould, and were afterwards bolted to them to give strength to the mould while the metal was being cast.

In building the mould the drawbacks were left to the last, as the joints or partings have to be prepared.

Cast-iron stiffening rings were bedded in the mould as it was built up, and when the last plate was bedded the whole mass was firmly secured together by hook bolts to the lifting plate, scores having been left in the brick work above the lugs and staples on the lifting plate for this purpose.

For the space between the cylinder and the exhaust passages two special plates were cast, having long prickers in them. The lower one of these plates was supported from the "drawback" plates, and had the loam and brick work built on it up to the dummy and patterns, but leaving space for the vertical strengthening rib connecting the cylinder and the steam chests at this part. These plates extended across the rib, and had the center parts cast into the rib, after which the ends were broken off.

The main "drawback" extended from the middle of the lower steam nozzle to the middle of the upper steam nozzle, and from the line of the cylinder foot around to the other side of the cylinder, as shown by broken lines on Fig. 3.

Care was taken to leave openings where the steam and exhaust nozzle cores cut through the sides, in order to secure the cores in place, and for inserting pipes for venting and conducting away the gases through the sides of the mould.

In order to have an equal distribution of metal throughout the mould when casting, especially around the steam chests, "runner sticks" were built in the spaces, being connected afterwards with the draw gates which conducted the metal into the mould.

The outside of the mould having been finished, the spindle was removed and a top or covering plate was cast in open sand, having openings in it for all parts of the mould that may project above it. As it bedded at the middle of the top steam port, openings were left for this port, the cylinder feet or lugs, etc., and for securing and venting the cores for the steam chests, steam jackets, piston rod, manhole, etc.

There were also openings for the gates in line with the thickness of the body of the cylinder leading to the top and bottom of the mould. These various openings allow parts of the different patterns to be withdrawn and give the moulder a chance to dress and finish the mould, and were afterwards covered by smaller plates secured by hook bolts to staples cast in the top plate.

Prickers or prongs were cast in the bottom side of the top plate, and the plate was fitted in place to see that these prickers were of the right length, the ends conforming closely to the top surface of the dummy cylinder.

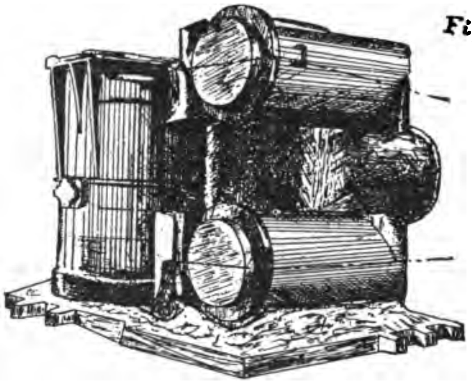


Fig: 3

The plate was inverted and bricks were wedged tightly between the prongs, so that they could not fall out when the plate was again reversed; the surface of the bricks was covered with a thin layer of loam; the plate was then put in the oven and dried. Sharp spikes were driven into the center of each core-print or jacket opening to serve as a guide for corresponding hole in the top plate. When the top plate was removed from the oven, it was placed on the "dummy" and fitted by rubbing and scraping till it had a good bearing.

This having been done, the top surfaces of the "dummy" and patterns were oiled and then covered with one or two inches of loam, and a clay wash put on the dry loam surface of the top plate to make the wet loam adhere to it. The top plate was inverted and lowered on the wet loam and gently rubbed to and fro to make the loam take a good impression of the cylinder and to squeeze out any extra loam; the closer it is rubbed down the better, as there would be the less moisture left to be absorbed.

Where there were any vacant spaces, as around the cylinder feet, "gaggers" were fitted in and bedded in the mass on the top plate and the openings then filled with loam.

The joints where the mould was to be parted were sleeked smooth and marked so as to serve as guides for connecting the parts again, and the top plate was then removed and inverted, it having trunnions on it to allow of this being readily done, and the surface of the loam was dressed and finished.

The inside "dummy" was next removed by picking out the bricks and removing the dry mud, and, if the loam surface showed any irregularities, the spindle was put in place and a sweep used to straighten it.

The patterns for the steam chests, brackets, ribs, etc., were next carefully removed, either whole or in sections, the drawbacks lifted away and the pattern for the lower part of the steam chest withdrawn, when the "drawback" was replaced and secured to the stiffening plates and lifting ring.

A strong iron cross beam having been attached to the foundry crane was swung over the mould, and links or slings from it were connected to the lugs or staples on the lifting plate and this was then lifted off the foundation plate, care being taken to lift it squarely off its seating by attaching counterbalance weights to the cross beam opposite the heaviest side of the mould. The cross beam has notches on the top sides to prevent the iron slings from slipping.

The mould was placed on a car convenient to the oven and finished by smoothing the uneven surfaces; filling up any crevices or hollow parts with loam, and the whole surface then washed over with a preparation of fine loam; the surface sleeked smooth with trowels or different shaped sleekers and then given a coating of liquid blacking applied with a brush.

This blacking consisted of six parts of pulverized charcoal, two parts of mineral facing, two parts of silver lead or graphite; the whole mixed with clay water, to which was added one-half gill of molasses.

For an extra finish the mould was again sleeked over and a camel's-hair brush used to wash it with a mixture of molasses water and graphite. This prevents the blacking from rubbing off after the mould has been dried.

This wash prevents the metal from burning into the surface of the mould. The top part of the mould was treated the same way.

When the "lifting plate" was removed a covering of loose sand was put over its seating to protect it and the building up of the main core began.

The spindle was put into place and a sweep attached at a radius to allow for shrinkage and for boring out the cylinder. The main core was built up with a double row of bricks next the sweep and the center part filled with loose bricks having fine cinders between them, to allow of free passage of gases to the vents through the openings for the piston rod and manhole, as there would otherwise have been danger of an explosion due to the accumulation of hot gases mixed with the air.

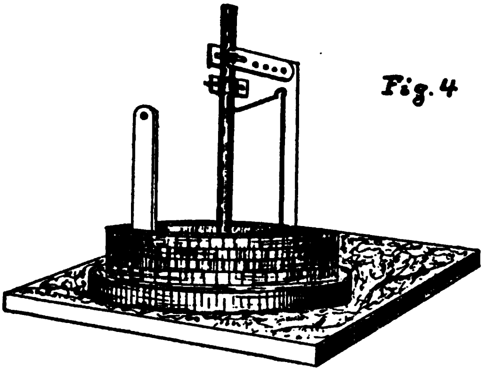


Fig. 4

The top was strengthened by a "crown" plate having prickers in it to hold the bricks and loam forming the top surface of the main core. This "crown" plate had a radial slot in it to allow it to pass the spindle, the slot being afterwards covered by a small covering plate bolted to the "crown" plate. One of the most important points in building the main core was the "relieving bar," which reached from the bottom flange to the inner thickness of the jacketed head, and was placed directly under the manhole opening.

This relieving bar was of iron, tapering from 3/4 inch at bottom to 1-1/2 inches at top and 8 inches wide. A hole near the top of the bar allowed a shackle to be attached and the bar withdrawn through the manhole, after the cylinder was cast, so leaving a clear space for the contraction of the metal while cooling.

The bar was placed with its narrow edge flush with the surface of the bricks. Fig. 4 shows this relieving bar while the main core was being built up.

Part of the port cores were swept up on the main core, to which they were secured by prickers on the "crown" plate, they being located by means of the center lines, and made to correspond exactly with the dry sand port cores in the steam chests.

The main core was made a little larger in diameter at the bottom than at the top, to allow for the pressure of the molten metal; the pressure being due to the height of the cylinder plus that of the riser head. In these cylinders 1/8 inch was allowed. This precaution also helps to prevent the core from floating.

In some shops an internal bearing is secured to the "foundation plate" and the main core built on it, so that when completed it can be lifted out and the moulder examine the cores for the ports, etc., and see that they are in place and have the right space for thickness of metal around them.

After verifying the dimensions of the main core, the spindle was removed, the core blackened and finished similarly to the other parts of the mould, when all parts were transferred to the oven, the joints having been blocked open to allow of the circulation of the hot air. It is best to dry the mould slowly at first to prevent too sudden expansion of the different iron plates, etc., and the blistering and cracking of the finished surfaces.

After about twelve hours the heat can be increased, care being taken that the mould is not burnt. It takes from forty-eight to seventy hours to completely dry the mould, which should then have a light brown color.

While the foregoing work was being done the "dry-sand" cores were being prepared. Wooden core boxes of the requisite shapes were used to make the steam chest and other cores.

Where the cores had to be rights and lefts, the boxes were made interchangeable. Core irons were cast to the shape of the box for stiffening the cores, and had staples for lifting cast in them, also "prickers" of wrought iron for holding the sand together. The core irons were made gridiron or herring-bone shape as more convenient for ramming the sand and easier to break out after the cylinder is cast. These irons had a feather or "V"-

shaped edge, so as to present the least possible resistance to the shrinkage of the metal.

The sand used was composed of eight parts of fire sand and four of coarse moulding sand, with one part of flour. If the sand is very moist one-half part of ground clay is added. The whole was well mixed together, then passed through a 1/2-inch mesh sieve and afterwards through a 1/4-inch sieve, then moistened with clay water and tramped or kneaded thoroughly, and finally again passed through a 1/4-inch sieve. The sand must be of the right consistency; if too dry, the core may crumble when dried; and if too wet, it will swell or crack in drying.

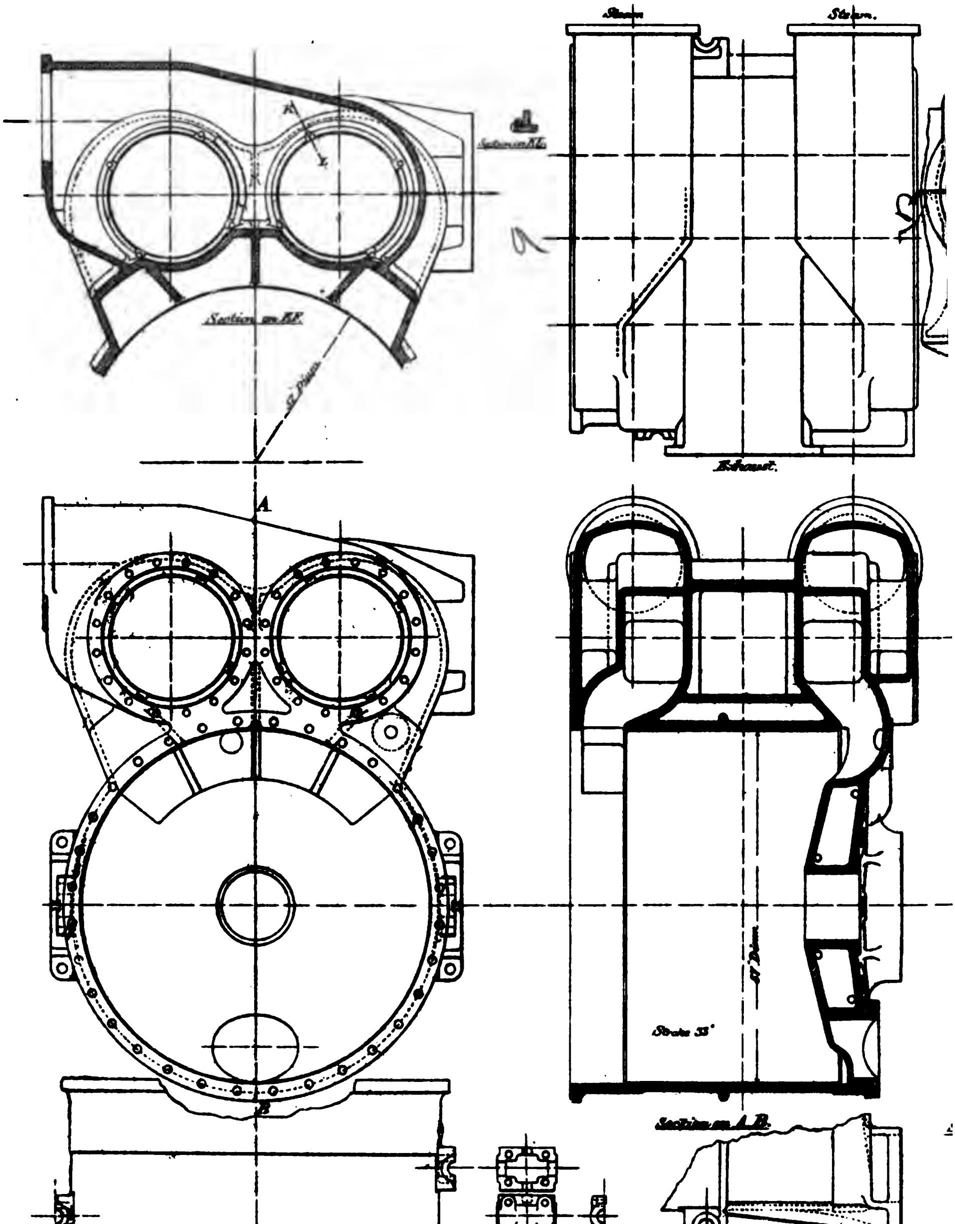
The flour and clay cement and bind the particles of sand together when baked in the oven; and, in the casting of the metal, the flour burns away and disintegrates the core, making it easier to remove.

Everything being ready, the core box, for example, that for one of the steam port cores, was laid on a solid foundation, and some fine core sand sifted through a 1/8-inch sieve over the bottom of the box; on top of this was placed a layer of sand 1/2 inch to 1 inch thick, and then the core iron having been clay-washed, was hammered down in the sand, and the sand rammed all around it and between the spaces in the core iron. Where there were any large open spaces, points or corners, rods or nails were bedded in and wired fast to the core iron to strengthen such weak parts.

The core having been rammed several inches deep, all parts were vented with a vent wire and the center of the box filled with cinders.

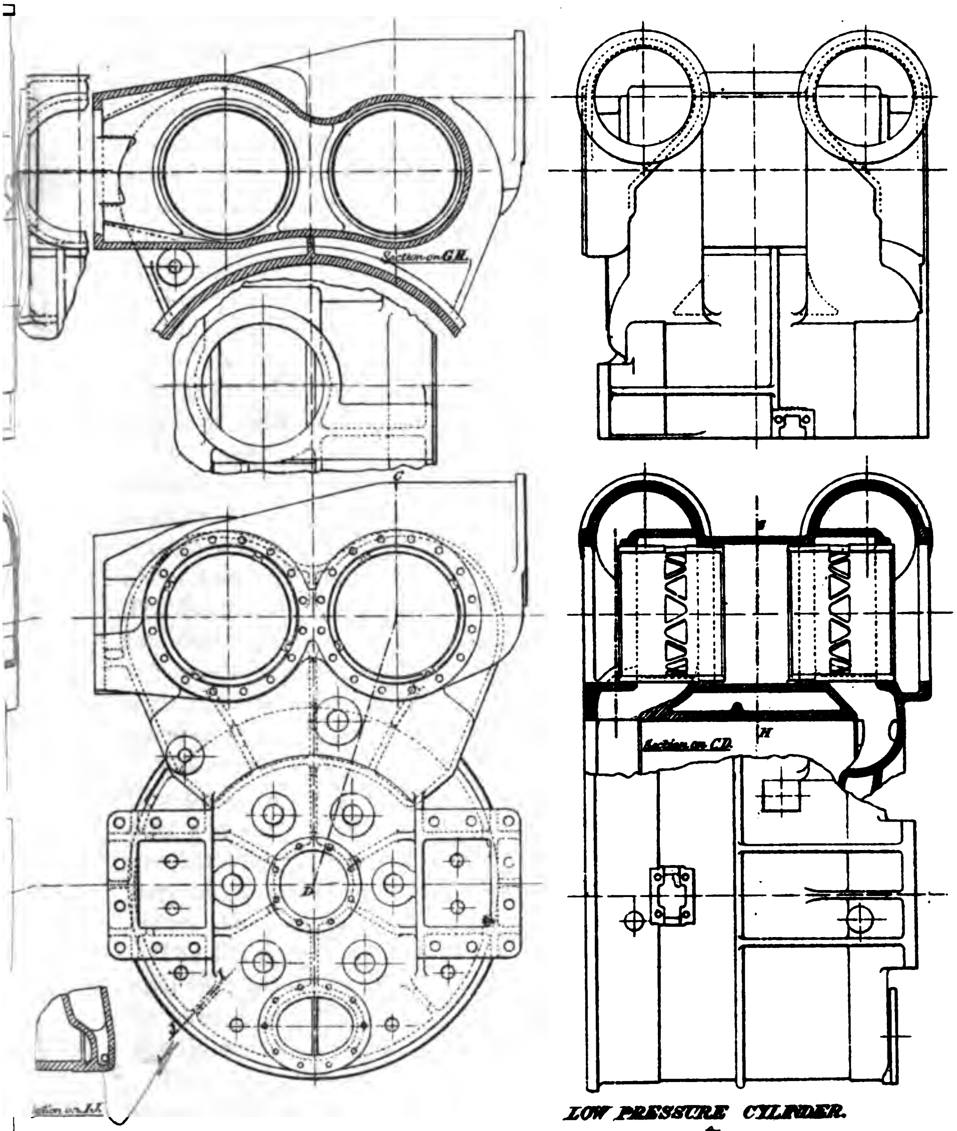
The core was thus built up till the top of the box was reached, when the top surface was vented into the cinders, the surface squared, moistened with clay water, sleeked smooth, blackened, and then had some dry parting or beach sand sprinkled over it, on which was packed some damp moulding or floor sand of sufficient thickness to cover all the projecting parts of the core iron, and a stiff plate large enough to cover the whole, bedded in the sand and clamped fast to the core box. The mass was then inverted, the core box loosened by rapping and carefully drawn off. The surface of the core was next finished and placed in the oven to dry.

The steam jacket cores were made in the same way, the core irons being cast from patterns and made very light, as they have



Steam
Steam.
Section on K L.
a
Section on E F
51" Diam.
Exhaust.
A
B
47" Diam.
Stroke 33"
Section on A B.

Figure 5.



LOW PRESSURE CYLINDER.
for
U.S.S. RALEIGH.
Designed by Bureau of Steam Engineering, Navy Department.
Cast at Department Steam Engineering
Navy Yard. New York.

to be broken up and drawn out of small holes after the cylinder was cast. A thread was tapped into these core irons and a tube bolt screwed in, answering as a vent and also to secure these cores to the top plate.

In building the cores, strings were run through them above the core irons and passed through saw cuts in the edges of the core boxes. After the core is finished in the box these strings are pulled out and the cores tested by puffing smoke or flour through the openings left—if clear the cores are used, but if not clear it shows that the core is not well vented and must not be used.

These holes are afterwards sleeked over with "slurry." In building up the main steam-chest cores, a wooden plug was built in the center of the core from the bottom to the top, which, when withdrawn left a clear vent to which all the port cores opened by means of their cinder centers.

The casting pit was dug in the floor of the foundry, where it could be readily reached by the cranes, and was of sufficient size to allow of a curb of sheet iron to encircle the mould. The sand thrown out was afterwards used for ramming purposes, so only about one-half the depth of the mould was necessary in the pit. The bottom of the pit was levelled to give a fair seating for the foundation plate.

Sometimes a channel is cut from the center of the pit and filled with cinders to conduct the gases from the main core, as the opening at the top may be too small for that purpose.

The mould and cores having been thoroughly dried, the foundation plate carrying the main core was placed in the pit, and all dust and dirt cleaned off, and the edges of all joints scraped to prevent shelling off or crushing when the other parts of the mould were put together. Generally the edges of the joints are scraped before the mould goes into the oven.

The lifting plate carrying the rest of the mould was next lowered into place, and the space for the thickness of metal gauged by putting in rolls of putty or soft clay and taking impressions of the thickness on them.

This thickness space being correct, the "drawbacks" were removed and the cores for the steam-chest nozzles, steam and exhaust ports were put in position, great care being taken to see that the proper thickness of metal was allowed for all round; that the cores matched properly and were exactly in their proper place. Cast-iron chaplets were placed in the thickness space between the cores, to serve as supports for the cores and to enable them to resist the pressure while the metal is being poured.

The chaplets are usually made of cast iron, being two plates connected by a stud of as small a diameter as possible, as it expands as the metal flows around them, contracting again when cooling and liable to show leaks when testing the cylinder. These chaplets are generally tinned or zinced over to give better joints in the casting.

It is necessary to be very careful of the joints where the different cores connect to the main steam-chest core, to prevent the metal from forcing its way into and choking the main vent should the cores happen to shift at all. To prevent this, short iron pipes of about the size of the wooden plug used in building up the steam-chest core are placed abreast of the joints, and damp facing sand rammed between the tube and the cores, completely filling the joint. Soft putty is also used for the same purpose, a thin roll being placed around the joint where the two cores connect, the putty helping to even up the thickness by being used thick or thin. The vent opening is filled with cinders to prevent it being choked, and to allow the gases to flow off regularly to the surface.

As the cores are placed, the "drawbacks" and "pockets" are put in their proper position.

The jacket cores were next secured to the top plate by means of the tube bolts tapped into the core irons (these bolts were protected by small hollow dry sand cores) and carried through openings in the plate; chaplets were used to retain the proper space between the cores and the top plate. The top plate carried the steam jacket, manhole and piston-rod opening cores; these having been secured in position, the top plate was inverted; soft clay balls placed all over the top surface of the main core, etc., to try the thicknesses, and the top plate lowered into place, and then removed, and the thickness space for the metal having been found correct, chaplets of the right size were placed where required, the clay balls removed and the top plate replaced in position.

The mould was prepared for binding and clamping together by stopping the joints and partings with slurry and inserting tubes into the cores to carry off the gases to the surface.

Iron packing or distance pieces were placed between the foundation and top plates to prevent the mould being crushed while being clamped and bolted together.

The heavy iron cross beam was then swung over the mould and secured to the foundation plate by iron links or slings, leaving about three feet between the bottom of the cross and the top plate; then the whole mass was tightened by lifting with the crane; iron packing or stays were placed between the cross and the top plate, one in the center and one under each of the four arms and finally the whole tightened by driving in iron wedges.

A few iron clamps were added to help the cross resist the pressure, especially around the steam chest, where there is an extra pressure from the cores.

The next process was placing the "curbing" around the mould; this consists of a cylinder made of thin sheet iron from one to three feet wide, the sheets being keyed or bolted together to form a cylinder, leaving about eight to sixteen inches between the mould and the curb. Vent sticks were placed to lead the gas to the top, and straw also placed against the brick work for the same purpose.

A course of sand eight or ten inches deep was thrown inside the curb, rammed down hard and then other layers added till the top of the curbing was reached, additional sheets being added as necessary. The sand at the bottom requires to be packed and rammed very hard with heavy iron-butt rammers, as there is a heavy pressure at that point. This is also done between the curbing and the side of the pit, which is also filled in.

The moulders used a pin rammer to ram the corners, and, as the sand was filled in, saw that the vent sticks were kept in place and new ones added where necessary.

The top of the curbing was about twenty inches above the top surface of the casting, to allow for a basin to pour the metal into, and a runner or flume to lead the metal to the gates; the bottom of the runner should be twelve or fifteen inches above the surface of the casting to insure a uniform pressure and to force the gas through the mould and cores; also to prevent the molten metal from bubbling and blowing by forcing it through the rising heads, which are flow-off gates placed generally on the highest and thickest parts of the casting for the purpose of feeding the shrinkage of the casting while it is in a liquid state.

The runners were next prepared by inserting "gate sticks" in the openings that allow the metal to flow into the mould; the vent openings secured by placing in them tubes large and long enough to prevent either dirt or metal from entering and choking them.

Some well-sieved, well-tempered moulding sand was packed and given a fair ramming for a depth of about fifteen inches, where the runners and basin were to be and also around the gates and risers, the surface levelled and packed by tramping over it. The basin was made about twenty-five inches diameter, and the channels from four to five inches wide and eight or ten inches deep, connecting the basin to all the gates. A flat, dry sand cake is usually placed in the bottom of the basin to prevent the stream of metal from the ladle cutting out the bottom. The surfaces of the basin and runners were smoothed and blackened, all loose sand and dirt cleaned away, and a place cut out around the risers, to hold about one hundred pounds of metal. Lumps of stiff clay, having lifting hooks in them, were placed over the risers and weighted down, to keep a pressure of air in the mould while the metal was being poured.

Shavings and straw were placed in the vents, and lighted just before the metal was poured, to ignite the gas.

The amount of metal necessary was calculated from the drawing, allowance made for metal to fill the gates, runners and risers, and then a surplus added to cover any accident or miscalculation; this surplus was afterwards cast into pigs.

The iron for steam cylinders should be very tough, strong and close grained. A good mixture is one-third of No. 1 American charcoal iron, with two-thirds of good machinery scrap, or if the machinery scrap is soft it will not require the pig iron, the melting bringing it down to the required strength. The metal used for the cylinders of the Cincinnati and Raleigh was all good machinery scrap.

The temperature of pouring the metal is very important. If too hot, the metal is more fluid, and has a greater penetrating power, and if there are any defects in the mould the iron is liable to find them out and create trouble; if too cool, the casting may show air or dirt holes while being machined, the metal not having sufficient fluidity to throw off the gas or float the dirt to the surface. The metal should be received hot from the cupola, and when cool enough to hang on an iron rod, should be run into the mould.

In pouring the metal the scum in the ladle was first skimmed off, then the metal poured slowly till the bottom of the basin was covered, then the stream increased, filling up the runners and keeping any dirt or scum floating on the surface till the mould was filled, which was indicated by the air blowing through the gates and risers, then the clay stoppers over the risers were lifted and the metal allowed to flow through, meanwhile keeping the runners full to increase the pressure.

When the metal in the runners became solidified, it was broken into pieces and thrown to one side, the sand cleared off the top plate, the iron cross beam hooked on to the crane, and the iron packing knocked out from under the beam; the way cleared down through the manhole to the relieving bar, which was hooked on to the crane and pulled out, to relieve the main core and prevent any danger of the cylinder cracking as the metal shrinks while cooling. The steam chest and nozzle cores were also relieved by having the cores partly broken up.

The curbing and sand were then removed and the outer parts of the mould relieved to prevent any interference in the shrinkage of the metal around such parts as the feet, brackets, etc.

The immediate safety of the casting having thus been provided for, it was left till the following morning, when it was still red hot, and the core irons of the steam-chest cores were broken from top to bottom by working through the steam-chest openings. After three days the casting was cool enough to take out of the pit by breaking away the brick work, burnt loam, plates, etc.; the cylinder was cleaned, all cores removed and all risers, fins, etc., chipped off.

Either before machining, or else afterwards, all parts where the steam comes in contact with the surfaces which are not machined, should be thoroughly pickled with a solution of muriatic acid in order to clean away all sand and grit that is partially burnt into the metal.

Great care was exercised by the moulders throughout the work, and the pattern makers who had made the patterns, sweeps, etc., constantly verified and corrected the sizes, locations, etc.

The above was the method adopted in casting the cylinders for the engines of the Cincinnati and Raleigh, and it proved very successful as not one was lost of the sixteen cylinders cast.

While being machined, the inside of the solid head and cylinder cover should be carefully gone over with a template or sweep to see that they are counterparts of the piston, as in moulding there may have been some irregularities of the surface which would diminish the clearance in the cylinder.

The finished weight of one of the L. P. cylinders is eleven thousand six hundred pounds.

The writer is indebted for valuable assistance in the preparation of this article to Mr. William Forbes, the master moulder in the Steam Engineering Department of the New York Navy Yard.

Question No. 2.—Describe the method of making a pattern for a cylinder or other complicated piece of machinery.

For full description see the Journal of the Society of Naval Engineers, Vol. IV, No. 2, p. 159.

For a small cylinder, the pattern is sometimes made by gluing together discs of white pine, thus making a solid cylinder, which is then turned down in a lathe to the required shape and size; the patterns for steam chests, etc., being made separately and secured to the cylinder by dowel pins. In all cases the particular point to be observed is that the pattern is built so that the mould will not be broken when the pattern is withdrawn from it.

The following description of a method of moulding a cylinder in dry sand at the Bath Iron Works is the one referred to above, and is by Lieutenant S. H. Leonard, U. S. N. It is here reprinted by the courtesy of the American Society of Naval Engineers.

METHOD OF MOULDING A CYLINDER IN DRY SAND AT THE BATH IRON WORKS.

BY LIEUTENANT S. H. LEONARD, U. S. NAVY.

Large steam cylinders are cast either in a dry sand or a loam mould. If by the former method, which is usually the case when they are more or less complicated and there are two or more to be made of the same size, a complete pattern is made and rammed up in dry sand in a flask. In the case of a loam mould, patterns are also required of the steam chest, steam and exhaust nozzles, and all brackets, webs, lugs, bosses, etc.; these are built into the loam work as the cylinder is swept up. The following description refers to the intermediate cylinder for the Katahdin. This cylinder is 36 inches in diameter by 36 inches stroke, and is designed for a liner 1 inch thick.

The work on the cylinder proper forming so small a proportion of the total required on the mould, there was relatively little that could be swept up, and consequently time and expense were saved by making a complete pattern and moulding in dry sand. There were two of these cylinders, so that one pattern answered for both.

The pattern was made of well-seasoned clear white pine. Such wood warps very little, is not likely to check or split, is light to handle, has a fine grain and is easily worked. A two-foot shrinkage rule was used, measuring 24-9/32 inches; or, in other words, a shrinkage of 9/32 of an inch was allowed in two feet.

In making the pattern, the barrel or cylinder proper was built up as follows: To three ring discs about 3 inches thick and 4 inches wide, one at either end and one in the center of the cylinder, are screwed longitudinal strips 3/4-inch thick and 5 inches wide, which are firmly glued to each other; secured to these discs at either end are four additional circular discs, each about 1-1/4 inches thick. At the stuffing-box end of the cylinder the four discs have a diameter equal to that of the *outside* of the cylinder, and after gluing together are turned out to the dished form called for in the drawing. The stuffing box is let slightly into this head and its webs located per drawing.

The lower discs are of the same diameter as the cylinder *inside the longitudinal strips.* The cylinder's lower flange is made up of circular strips, breaking joint, firmly glued to each other and then turned to size, its internal diameter being the same as that of the lower discs over which it is slipped, leaving about 2 inches of the disc projecting, which forms the cylinder core print.

The steam chest is made in the same general manner in five separate box sections, two steam ports and three cylindrical sections of steam chest. The cylinder and steam chest are each provided with axial holes for the insertion of iron rods for the purpose of drawing them from the sand. The steam ports, steam chest, lugs, bosses, stuffing box and its webs, brackets and cylinder flange, are all fitted to the barrel of the cylinder with wooden pins; these are removed—where necessary in drawing the pattern—as the mould is built up.

The pattern when complete receives a coating composed of lamp black, shellac and alcohol, which gives it a smooth, glossy surface, filling the pores of the wood and preventing the absorption of moisture. In order to prevent any chance of mistaking a boss or projection for a core print, the latter receive a coat of shellac only, which leaves them a bright straw color.

The pattern maker, after finishing the cylinder, turns his attention to the necessary core boxes and sweeps. These are made as simply as possible, often consisting of only a skeleton frame, as is well illustrated in the sketch of the frame for the steam-port cores, Plate 3, Fig. 8. This consists of three distinct parts; the circular portion A, consisting of strips of wood glued together, and to which are secured the side pieces B; the reverse curve piece C, made up as shown; and the skeleton piece D, screwed to the top of A, and which carries a small section of the steam chest E. Fig. 3 shows the construction of the core box for the exhaust nozzle, one-half of the core being formed at a time, and the two halves joined, after baking, with a thick flour paste. The same construction is used for the steam nozzles, Fig. 5.

The frame for the cylinder core is made up of circular strips, as shown in Fig. 9; it is 6 inches deep, and is made up in sections, as shown in Plate 2, Fig. 2. The frames for the steam-chest cores, Fig. 6, are made in a similar manner in two rings corresponding to the two diameters of core; they are fitted to each other by a small lip turned on the edge of the upper ring; when ramming up, the frames are held together by means of several staples driven into their outer surfaces. The core boxes are all made of the same material as the pattern, and receive the same black coating on their internal surfaces. The sweeps, Figs. 2 and 9, are simply wooden strips cut to the proper shape from dimensions taken from the drawing, and in use are secured to a central iron spindle as an axis, about which they are worked; their bearing edges are beveled for the purpose of leaving the sand freely in sweeping.

The pattern being now ready for the foundry, the first work in the latter is the casting and fitting of the flask, which in this case consisted of eight sections, five of which were 7 inches and three 12 inches deep, all being 8 feet 10 inches long by 6 feet broad outside. The same flask was used for the H. P. and I. P. cylinders and also the same sides for the L. P. cylinder, new ends (longer) only being required in the latter case. These flask sections were cast from a pattern in green sand. A base plate 1-1/2 inches thick and of the same dimensions as the flask is cast in the open sand without a pattern, its outline being marked off with the aid of a straight edge on a prepared body of sand on the

foundry floor; a strip of wood 4 or 5 inches wide and about 2 feet long, with a thickness slightly greater than that of the plate, is used for tamping the sand against, the strip being gradually worked along the line until the mould is complete.

A pit about 2-1/2 feet deep is now dug in the foundry floor, into which three cast-iron resting bars, 4 inches by 5 inches, are lowered and adjusted with a spirit level. Upon these the base plate is placed, which in turn forms the support for the lower flask as shown in Plate 1, Fig 2. The lower flask is rammed up with *green* sand and then scraped off with a straight edge to about 2 inches below the top of the flask. The barrel of the cylinder is now placed in its proper position in the flask and the pattern made complete by pinning on the steam chest, nozzles, legs, etc., the whole pattern resting on the core prints of the cylinder and steam chest. The lower flanges are held in place and the whole nicely adjusted by wooden wedges placed under these flanges. The pattern is now given a coating of light machine oil applied with a cloth or bunch of waste for the purpose of preventing the sand from adhering to the pattern, as well as to constitute an additional safeguard against the absorption of moisture from the damp sand. The remainder of the lower flask is rammed up with *dry* sand which is carefully tamped under the cylinder and steam-chest flanges, lower bracket and steam nozzle, the wedges being removed as the work goes on. The sand in this flask is built up to the level of the top of the lower flange of the cylinder. In ramming up, each section of flask acts as a partial cope to the one immediately below it, and therefore the parting surface must be so made that each flask may be raised in turn without breaking the mould. The line of each flask joint is shown by heavy dotted lines in Plate 1, Fig. 2.

The dry (facing) sand is mixed as follows:

6 pails new loam sand.
6 pails beach sand.
1 pail flour.
1-1/2 pails clay water.
1/2 pint molasses.

Parting sand is now sprinkled over the lower flask and the second section is lowered into position. The next operation is to fit thin cast-iron brackets to the sides of the flask to form a support to the sand. These brackets are cast in the open sand and along their lower edges nails are cast in, Plate 2, Fig. 1. They are spaced about 6-1/2 inches apart and are secured with 1/2-inch bolts passing through the vent holes in the sides of the flask; they are slightly less in width than the depth of flask section to which they are fitted, and are of varying lengths reaching to within about an inch of the pattern; they are cast with several holes about 2 inches in diameter for the purpose of locking them in the sand and also to reduce their weight; these brackets all receive a coat of clay wash to ensure the sand adhering to them. Facing sand, mixed as above described, is now shoveled in the flask and carefully rammed in all around the pattern, and to about an inch in depth all over the bottom of the flask. To give additional strength to the sand, cast-iron gaggers 1/4 inch square in section, with legs about 3 inches and 6 inches long respectively, are bedded in the sand alongside the brackets, after receiving a coat of clay wash; gaggers about 10 inches long are bedded horizontally. These gaggers are worked in as the flask is rammed up, facing sand being used to a thickness of about 2 inches around the pattern, and foundry or green sand filling in the intervening space to the sides of the flask. This sand is made a little more open than ordinary green sand by the addition of fine gravel, and to maintain its strength it is dampened with a thin clay water. The upper portion of the flask to about an inch in depth is rammed wholly with facing sand, over which, after sleeking, is strewn the parting sand. As stated above, the pins securing the bosses, brackets, etc., are removed as these parts become securely bedded.

The successive flask sections are rammed up in the same general manner as described. In some of the sections, however, the pattern falls away considerably from the sides of the flask, in which case, to give sufficient support to the large body of sand, extra sides are bolted between the flask ends, brackets being bolted to these in turn as well as to the outer sides; this is shown in Plate 2, Fig. 1, which is a section of the mould with the fourth flask in place ready for ramming, the pattern being removed and the cores in position.

The body of sand between the steam chest and the cylinder is supported by four 5/8-inch round iron rods—two in each flask—bolted to the side plates; to these rods gaggers are wired as shown. This body of sand is side-vented with the vent wire. It is of course understood that the sand around the *cylinder* is sup-

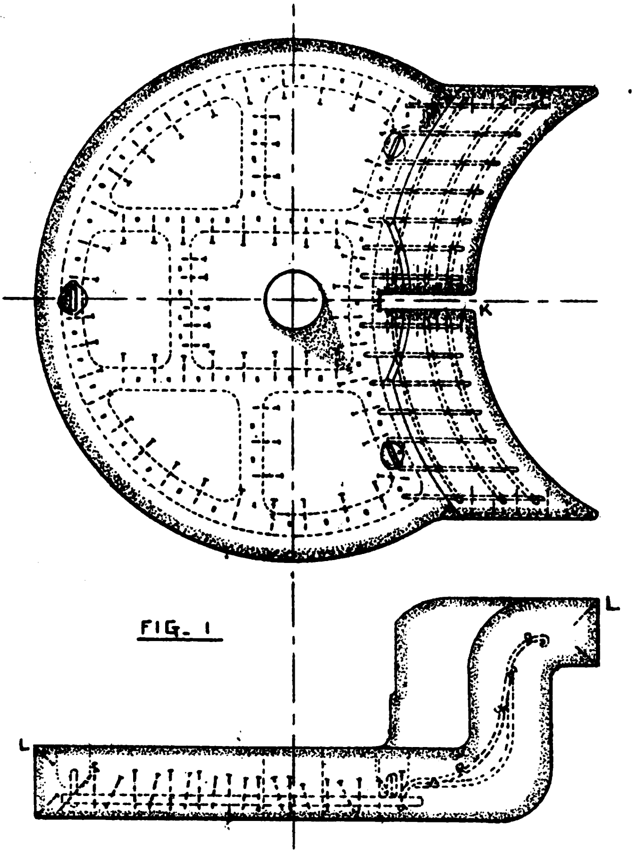


FIG. 1

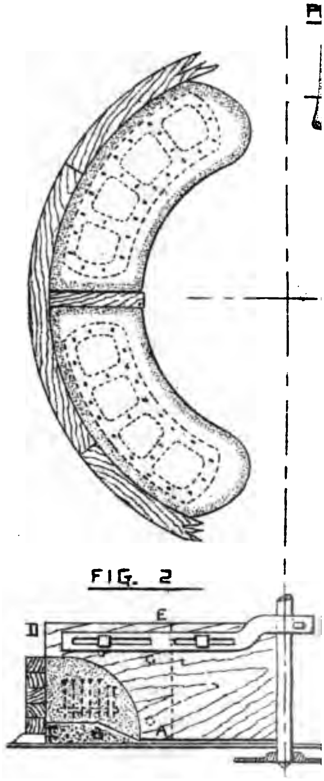


FIG. 2

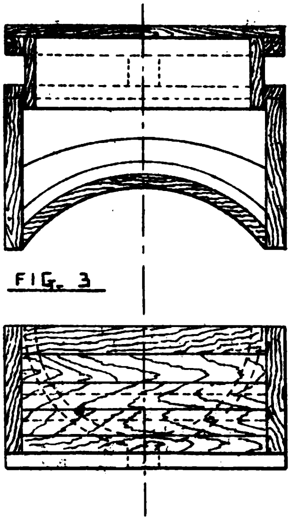


FIG. 3

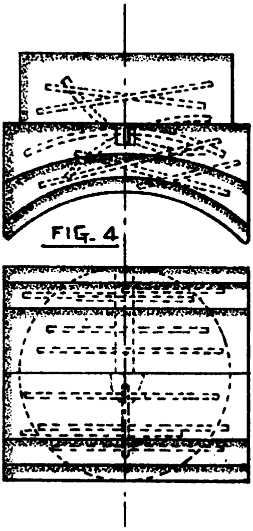


FIG. 4

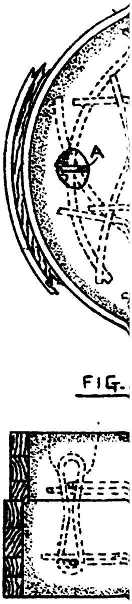


FIG.

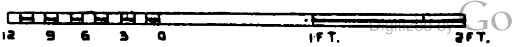


PLATE 3

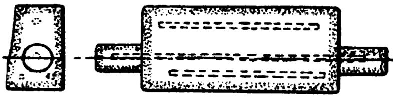


FIG. 7

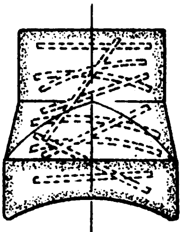


FIG. 5

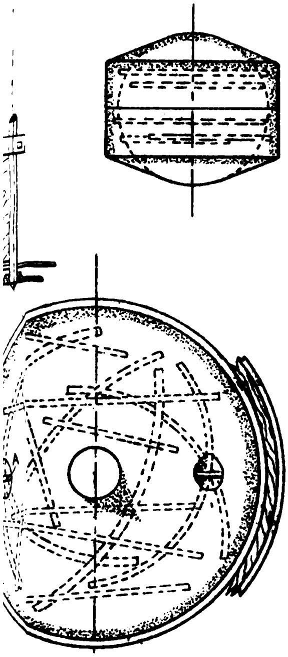
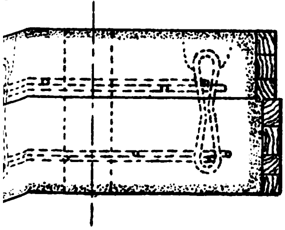


FIG 6



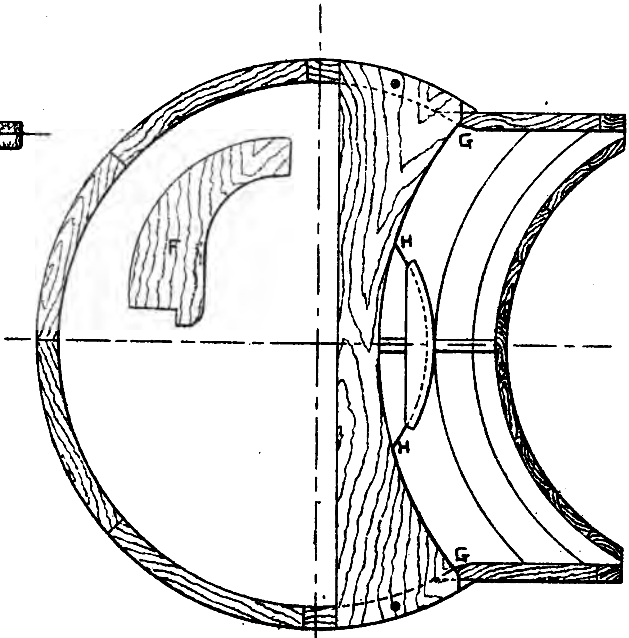
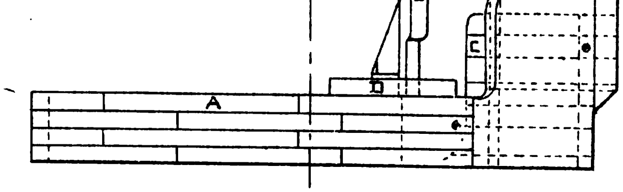


FIG. 8



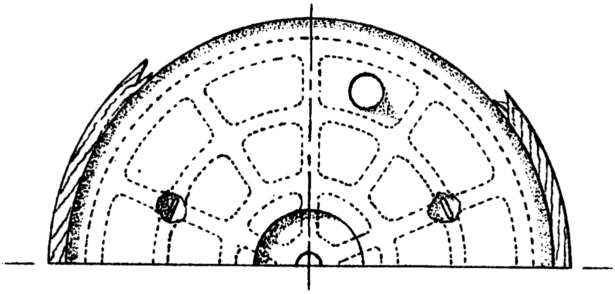
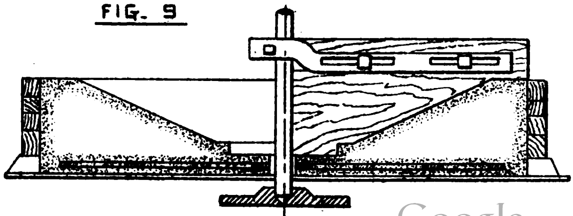


FIG. 9



ported in the same manner by nails, gaggers, etc., as about the steam chest, although not filled out in the drawing. In making up the cope, cross plates are bolted to the flask sides and the sand firmly rammed between them, the gate sticks—1-1/2 inches by 1/2 inch—also vent and riser plugs, being previously placed in position. In order to properly ram the sand under the brackets G, H, K, Plate 1, Fig. 1, square pieces are cut out of the pattern as shown at H, and after the ramming are replaced. These pockets of sand are also side-vented with the vent wire. To give support to the hanging sand between the webs surrounding the stuffing box, thin bracket plates are suspended by wiring from the heavy cross-plates, and alongside these latter, all through the cope, are imbedded numerous gaggers, brackets, nails and wires. The upper surface of the cope does not receive a layer of *dry sand*, as is the case with the other flask sections; unlike the other sections, also, it is well top-vented with a light vent wire.

The following portions of the pattern remain in the cope upon its being raised: the stuffing box and webs, the cross-head slide bracket, steam-chest core print, the upper half of steam nozzle, and the top sections of upper steam port; the two latter are held in place by means of wires secured to them, passing through to the top of the cope where they are secured.

The cope is now swung by the crane to an available place in the foundry floor and turned bottom up. The sharp corners of sand are trimmed off with a trowel, and nails impressed where necessary to give additional strength. The different pieces of the pattern are now carefully drawn, the mould sleeked and given a coat of black wash. The stuffing-box flange is detachable and is cut obliquely in order that it may be drawn after removing the stuffing box proper. The cylinder proper, with its two side brackets, M, N, is now drawn from the sand by the aid of an eye-bolt screwed into an iron plate secured to the lower discs; the lower flange is left in the mould. The upper section of the steam chest, lower half of steam nozzle, and the cylinder legs, are now drawn; also the several bosses which were attached to the cylinder. The mould of the latter is given a coat of black wash.

The second section of flask is now raised, which exposes the pattern of the upper steam port, which is accordingly removed, and thus the work of alternately removing flasks and sections of pattern continues throughout the mould. As each section of flask is removed it is gone over carefully with a sleeker, any broken edges, cracks or other defects repaired, and the face of the mould is given a coat of black wash. After this treatment the flasks are all piled upon two low iron platform cars and wheeled into the drying oven.

The sand for cores is mixed as follows: 10 pails of beach sand, 1 pail of flour, and 1-1/2 pails of clay water. The flour and clay water give the core strength or cohesion when ramming, and render it firm and solid when baked.

In making the core for the steam ports, Plate 3, Fig. 1, the core frame, Fig. 8, is placed upon a small platform car, the top of which was previously sprinkled with parting sand to prevent the core from adhering to the plate after baking; a vent plug about 4 inches in diameter is placed in the center of the box, and sand prepared as above is added to a depth of about 2 inches. The frame, shown dotted in the core, after receiving a coat of clay wash, is now placed in position. This frame gives the core the necessary strength for handling, and is cast in the open sand, the outline being laid off with dividers and straight edge, and the sand then scooped out with a sleeker to the proper depth. The two nests of bent wires (1/4-inch diameter), three lifting staples and a quantity of nails, are printed in the mould before pouring; the nails are bent *ad libitum* after the casting is cold. More sand is now added, and when the core box is a little more than half full, a net work of gravel is laid on, radiating from the vent plug; this gives the core a free vent for the gases when pouring. More sand is added and well filled in around the wire frame forming the upper portion of the core, the whole being well rammed. The frame piece D is screwed in place and the sand rammed up to the top of the core box. By the use of two sweeps, one of which is shown at F, the upper portion of the core is trued up; the sweep F is provided with a lip, by means of which it is guided along the curve GH, and so sweeping the upper portion of the core between G and H, the second sweep completing it from H to H. The frame D is now removed, the body of the core leveled off with a straight edge, and the whole carefully sleeked. The screws securing the reverse piece C to the sides B are removed, and the circular frame A raised from the core, after which the reverse piece is drawn away. Thin pieces of iron are braced against the sides of the core at B to support the sand until it gains strength by baking; for the same purpose the web space K, Fig. 1, is packed in with green sand. The sharp edges are trimmed off and nails impressed along the corners, as shown at L.

The core is now wheeled into the oven, and in this case was baked 36 hours under a low fire. Shortly after removal from the oven, the core receives a coat of black wash, consisting of pulverized Lehigh coal mixed in water. The core contains sufficient heat to thoroughly evaporate any moisture resulting from the wash.

The method of making the steam-chest cores is shown in Fig. 6. A vent plug 4 inches in diameter is placed centrally in the core box, and sand shoveled in to the depth of about an inch, when two links, A, A, for lifting, and a number of core irons are placed as shown; sand is again added and rammed up to within about 2 inches of the top, when more core irons are laid, after which the whole is completed with additional sand, which is finally leveled off with a straight edge. After rapping, the rings are lifted one at a time, the core plug removed and the sharp corners of the core trimmed off, when it is placed in the oven, where it remains 24 hours. When taken out it receives a coat of black wash on its circumferential surface, the part coming in contact with the molten iron.

The upper sections of the upper steam-port core were swept up, as shown in Fig. 2. A primary sweep, ABCDE, secured to the finishing sweep, was first used for forming a green sand foundation ring, BC, after which core sand is built up on the green sand, a core frame being added, as shown. The finishing sweep completes the core. After baking, the green sand section is scraped away.

The main cylinder core, Plate 2, Fig. 2, is made similarly to the steam-chest cores; the upper section, however, is built upon a core frame and swept up, Plate 3, Fig. 9. Although this section of core was 7-1/2 inches deep, the same core box was used by propping it up on distance pieces, thus making one core box answer for all the sections. A core plate is used in the lower section of core, and into which three strong lifting staples are cast. As the whole weight of the cylinder core is taken by these staples, their attachment to core *irons* would be insufficient, and hence the core *plate*. These core sections were each baked 24 hours, after which they were made up as follows: The lower section was placed upon a foundation plate, AA, Plate 2, Fig. 2, and adjusted with a spirit level, after which the succeeding sections were placed one upon the other, a ring of dry flour making an even joint in each case.

It should be said here that, in general, it would be simpler and cheaper to sweep up a core like this in loam. The method described was adopted because the loam moulders and the whole of the foundry devoted to loam work were busy on other parts of the machinery.

To give the core (which is now of a uniform diameter) the contour of the internal surface of the cylinder, a sweep is used swung from a central spindle, which passes through the hole in plate AA. The sweep is first adjusted *vertically*, and the heights B, C, D, E, F located; the sand is then cut out between AB, CD, EF to the proper depth (according to the sweep) for a short distance circumferentially, with an old saw and rasp file, when the sweep is adjusted *axially*, and the sawing and filing continued around the core until the sweep neatly clears. The joints G of the sections are finished by scraping out a groove 1/4 inch wide and about 4 inches deep, into which fresh core sand is tamped, sleeked and black washed. The whole core is tied together by means of a 5/8-inch round iron rod passing through the central vent and secured to the frames in the upper and lower core sections. The stuffing-box core is united to the main core with a flour paste joint. The whole core is now given a coating of plumbago mixed in water, to which a little black molasses is added, which ensures the casting peeling well. After this treatment the core is placed in the oven over night, when it is ready for the mould. The joints between the different sections of the cylinder core aid in venting, rendering the use of gravel, as mentioned for the steam-port cores, unnecessary. In fact, in a mould such as is now under consideration, the large body of dry porous sand contained in the flask allows of a large absorption of surface gases, and therefore very little venting is required in comparison with *green* sand moulds, where steam has to be contended with.

The mould after remaining in the oven for nine days * under a slow fire was removed, and the sections piled one upon the other in regular order in some available place on the foundry floor within radius of a swinging crane. After carefully leveling the foundation bars, already referred to, and adjusting the base plate, the first or bottom section of flask, which is the top one as piled, is lowered in place by aid of the crane and adjusted with a spirit level. This flask contains the core prints for the cylinder steam chest and lower steam nozzle cores. The order in which the mould now goes together is as follows: Lower section of steam chest core; lower stream nozzle core; 2nd section of flask; lower steam port core; cylinder core; 3rd section of flask; middle section of steam chest core; 4th section of flask; exhaust nozzle core; 5th section of flask; upper steam port core; 6th section of flask; upper section of steam chest core; upper sections of upper steam port core; 7th section of flask; upper steam nozzle core; water valve core; cores for side brackets; 8th section of flask or cope.

---

* It is not necessary to leave the mould in the oven as long as this, four or five days being ample time. It was done in this instance while waiting for the completion of the cores.

The flask sections are joined as follows: While they are suspended by the crane previous to lowering into position, the moulder removes any loose sand from their under sides by going over them with a brush; he then goes around the lower edges of the *mould* with a trowel, scraping away a little of the sand, which results in leaving a thin fin on the surface of the casting. If this were not done, the edges would bear on each other and the corners would be crushed and broken all around the mould at each flask joint. Any cracks which may have occurred while baking are filled in with sand and plumbago mixed with a little molasses water. The edges and cracks (if any) are now painted with oil to preserve their coherence; in fact, the oil is used on a dry sand mould for much the same purpose as the water swab in green sand moulding. The top of the previous flask, already in position, is now brushed off and a trail of dry flour laid around the mould a few inches from its edges for the purpose of forming a joint with the following flask, which is now lowered in position. Between the steam-chest core sections is placed a ring of flour paste encircling the central vent preventing any chance of the molten iron working into the vent in case of any unevenness of the joint. All the core joints are smoothed off with plumbago and sand as described above for the mould.

The cores for the steam and exhaust nozzles are vented by means of a 3/4-inch hole drilled several inches deep into the center of their core prints before they are placed in position; leading to these are holes drilled in the mould horizontally from the outside of the flask and filled with cinders. The cores for the side brackets are vented through the top of the cope. These cores are held in place by means of chaplets which are the only ones used in the mould excepting one for the water-valve core. The two upper sections of the steam-port core are joined to the cylinder core with a paste joint, and they are also secured by means of wires passing to the core frame of the upper section of cylinder core.

As the mould is built up, the spaces left for the necessary thickness of metal are carefully tested and corrected, if necessary, by shaving the cores; they are kept filled with waste to prevent anything accidentally dropping into the mould. The holes in the cylinder cores for the lifting rods are now filled with cinders, smoothed off on top with moulding sand and painted with oil. Before placing the cope in position a number of wads of stiff clay are set upon the top of the cylinder core at different points; also on the steam-nozzle core. The cope is now lowered in position, and, upon raising it again, these wads show the thickness of iron left for the cylinder head, nozzle, etc., any variation from the thickness called for by the drawing being corrected by shaving or patching the cores. In the case under consideration, there were practically no changes, and a slight shaving of one or two of the cores was all that was required, the mould going together without alteration. The cope contains the prints for the stuffing box, steam chest, upper half of upper steam nozzle, and side-bracket cores, by which they are held in position while pouring. A ring of flour is spread around, and the cope finally placed in position, completing the mould.

Three heavy iron cross bars, similar to the foundation bars, are placed upon the cast-iron distance blocks A, A, A, Plate 1, Fig. 2, resting upon the top of the flask. The upper and lower bars, which project beyond the flask, are tied together with wrought-iron stirrups and straps, and by means of wedges between the bars and blocks the whole flask is strongly bound together. A rectangular wooden frame 10 inches deep and sufficiently large in area to enclose the feeding gates is built up on the cope under the cross bars. A 2-inch iron vent pipe is led through the cope to the cylinder core, the gate sticks put in place, and moulding sand shoveled into the frame and rammed up, forming a green sand basin with a circular runner to supply the twelve feeding gates. As far from these gates as possible (outside the frame) a 2-inch hole leads through the cope to the flange of the upper steam nozzle, serving as a riser and overflow. The sand is built up around this riser for several inches, in order to give the mould a slight additional head. Another hole through the cope serves as a vent to the steam-chest core. The mould is now ready for pouring.

The cupola used is of the McKenzie type, 48 inches internal diameter, and 10 feet high from hearth to charging doors. After daubing up with clay, the swinging bottom doors were propped up in place, and the melter, entering from the charging doors, lutes the joints between the doors and the base of the cupola with clay, after which sufficient foundry sand is shoveled in at the breast hole to form a bed 6 or 7 inches thick. This is rammed and graded off towards the breast hole, which is now plastered up with clay and bricks, a pipe the size of the tap hole having been previously placed in position. The spout of the cupola is lined with clay and dried with a wood fire.

A couple of bushels of shavings and chips are thrown in, upon which logs of split pine are placed endwise on a slant against the sides of the cupola, thus protecting the luting as well as catching fire quickly; smaller pieces are thrown in between, and over all are thrown 18 bushels of fuel consisting of equal parts of coke and anthracite coal (675 lbs. coal; 360 lbs. coke). The cupola was lighted through the tap hole at 11.45 A. M. At 12.30 eight bushels more of fuel were added (300 lbs. coal; 160 lbs. coke), and at 1 P. M. commenced charging iron. At this time the bed of fuel was burning freely and had settled to about four or five feet below the charging doors. In this case no scrap was used, the mixture being composed of two parts No. 2 charcoal pig and one part No. 1 Sloss pig, which is a soft gray iron made from ore mined in Alabama. The pigs were all broken in two, giving the pieces a length of about 12 inches. About 2800 pounds of the iron is charged at a time, and a shovelful of oyster shells is added for a flux, and over all six bushels more of fuel (225 lbs. coal; 120 lbs. coke). This operation is repeated three times, which fills the cupola well up to the charging doors which are then closed.

(Note.—The mixture of pig here given does not represent the practice of the Bath Iron Works, as it was used to comply with the Navy Department specifications. In their own work, the mixture is changed by substituting, for about one-quarter of the charcoal pig, good clean scrap, such as broken car wheels. The cost of the two mixtures is about the same.)

The blast (centrifugal blower) was started at 2.45, and 15 minutes later the molten iron made its appearance at the taphole, which was then closed with a plug of clay on the end of the bot stick. A five-ton ladle, which has had a pine log fire burning in it for several hours, is placed under the spout and the cupola is tapped at intervals of five or six minutes for an hour, at which time there is sufficient iron for the cast, the ladle being nearly full. Sawdust has been thrown into the ladle from time to time to check radiation. This may seem somewhat strange at first sight to those not accustomed to this use of sawdust, but experience shows that it works admirably. The sawdust is not entirely consumed but becomes carbonized and thus acts as does charcoal in the more usual practice. The layer of charred sawdust, when the ladle is full, is about two inches thick.

The ladle is now skimmed and transported to the mould by means of the crane. Just before pouring, fine sand is scattered over the molten iron to form a thin crust and gather any remaining slag and scoria. A piece of oily waste having been placed over each vent pipe and lighted, the iron is poured into the basin until there is a free discharge from the riser; more iron is afterwards slowly added until the discharge from the riser begins to clog. There is a free discharge of gas from the core vents, the flame rising from 2 to 3 feet high, and all around the sides of the flask are numerous small jets of burning carbonic oxide. Shortly after pouring, the basin is taken apart and the gates broken before they cool. The overflow from the riser is run into pigs in the foundry flow by means of a wooden trough lined with moulding sand.

The following morning, the bolts securing the brackets to the sides of the flask are first removed, after which the flask sections are lifted off in order, the cores are dug out and the casting finally taken to the cleaning room. Here the fins are chipped off, and the sand thoroughly removed with stiff wire brushes, leaving the casting ready for the machine shop, in which condition it weighed 8170 pounds.

The H. P. and I. P. cylinders for the Machias and Castine, and all the cylinders for the Katahdin, fourteen in all, were moulded in the same general manner as described above, and with excellent results, none being lost and the castings coming out smooth and free from blow holes or other defects.

Question No. 3.—Describe the method of making a propeller pattern.

Two wooden guides faced with strap iron are gotten out, one being placed near the root of the blade and the other just beyond the periphery. The pitches of these guide irons are different, being *less* than the desired pitch near the root of the blade, and *greater* at the periphery. The guides, etc., are laid off with a shrinkage rolled 3/16 inch to 1 foot. About 1-inch white pine is used, planed on both sides. A rough outline of the palm of the blade is cut out on one end and then one edge is planed smooth; the lower edge represents the generating line starting from the axis of the hub, and at right angles to the axis or otherwise, as called for by the drawings.

Grooves are then worked into this board where it comes on the guides, so as to give a perfect bearing at the bottom of the grooves on the guides, and so that the edge representing the generating line comes flush with the guides. A second board is treated the same way, and, when fitted to the guides, is glued fast to the first board. Others are added in the same way till a little more than the full width of the blade is obtained. Then the built-up block is worked down till the edges representing the generating line in the different positions are all in one surface, which will then represent the go-ahead driving face.

The center line of the blade having been marked on the block, the size and form of the blade is laid off from it by measurements given on the developed blade of the drawing; this gives the outline of the blade, and the block is worked down to it. The thickness is determined by drilling the holes through the pattern at different points, and pegs of the required length (as shown on sections of blade) are driven in flush with the planed surface and secured by gluing. The pattern is then turned over and worked down to the thickness shown by these pegs; the palm of the blade is worked into shape according to drawing; the core prints are fitted for bolt recesses; the root of the blade is faired off to suit the eye; and the pattern is finally smoothed and shellaced.

Another method for making a propeller pattern is to cut out a lot of strips having a section 1 inch thick with one edge beveled to suit guides. These are placed with their beveled edges on the guide irons, and the strips are glued together, none being added until the full face of the blade is made, when the beveled faces of the strips give the true driving face. The palm is built onto these strips, the center line is laid off, the developed profile of the blade is drawn on the face, the blade is cut into shape, the thickness is determined from the strips, which are all of uniform depth, and the back of the blade is worked into shape.

The pattern for the hub is then made, generally spherical, with the recesses for the palms of the blades. This pattern is staved up and turned to shape in the lathe. Core boxes are made for the cores, for the recesses in the palms of the blades, where the bolts are put in, for the hole through the hub for the shaft, and for the cores which are used to lighten the hub and the palms of the blades. Patterns are made for the covering plates for the recesses in the palms, so as to give a smooth surface to the hub when finished.

Question No. 4.—Describe the method of moulding a propeller by sweeping up.

In modern practice most of the large propellers are built up, that is, the hub and blades are cast separately and then fitted together, so that the pitch can be altered if found necessary, or a new blade put in place of one broken without having to replace the whole propeller.

When made in this way, the hub is generally cast from a pattern, though it could also be swept up. A pattern is made for the palm of the blade. For the blades, a foundation plate is made in open sand. It is levelled and the spindle put in position. A layer of bricks is put on the plate and covered with loam about 1/2 inch thick where the guide irons are to be placed, which is swept up to give a seating for the guide irons. The center line of the blade is also marked on these seatings, which have been dried. The pattern of the palm of the blade is secured in position, being fastened to the spindle and squared up from the center line on the seating. This palm must be placed very accurately to avoid having the blades thrown out of shape.

It is necessary to use two guide irons, one as near the palm as it can be placed, the other about 6 inches beyond the end of the blade. It is found that, in casting the blades, the pitch near the root of the blade always *increases* while that at the periphery always *decreases*, so an allowance is made by *reducing* the pitch of the inner guide iron and *increasing* that of the outer guide iron.

For the Cincinnati and Raleigh using a 13-foot 6-inch diameter true screw, with a pitch of 15 feet 6 inches, the allowance made was 6 inches smaller pitch at 2 feet 1-1/2 inches from center of screw, and 3 inches greater pitch at 7 feet 3 inches from center of screw.

The guide irons and palm having been placed, the space between the guide irons is filled in with bricks, between which are rammed fine cinders, until the surface is about 1/2 or 3/4 inch below that given by the sweep. Then the bricks are covered with loam and the sweep is used to give the surface of the driving face of the blade. After this is swept up and sleeked smooth, the center line is transferred to it from the seatings and guide irons, and the center line is drawn on it.

The inner guide iron is now taken away, and the core prints for the bolt recesses are put in place. Then the brick and loam work is built up to the palm, and the root of the blade is smoothed in by hand.

A seat is prepared for the cope. A layer of parting sand is put over the swept-up surface of the blade, thickness strips giving section of the blade at different radii are put in their position as shown by the center line, and the spaces between them are filled in with damp moulding sand, gently rammed and stricken smooth, to give a fair surface with the thickness strips. This gives a copy of the back of the blade. The root is again faired in by hand and the surfaces oiled. The cope is built up of a number of flat plates bolted together and made to correspond closely with the back surface of the blade. It is put in place on the seating prepared for it, and is clamped fast to the foundation plate. A clay wash is put on the cope to make the loam adhere to it, and a layer of about 3/4 inch of loam is laid over the image of the blade. Bricks are then bedded in it, care being taken to wedge them tightly in the cope, loam being used at the frames of the cope to help hold the bricks. The joints are covered over and marked to ensure the cope going back into its exact place. The cope is removed, the sand blade and the thickness strips taken away, the palm is removed, the surfaces are sleeked smooth with slurry where necessary, vents and risers are provided for, as is also the gate into the mould. The surfaces are then black washed, and the mould dried in the oven.

This having been done, the cores for the bolt recesses and for the recess in the face of the palm are placed in position, and the cope is secured in place, after which the mould is put into the pit, etc.

The metal must not be too cool when run, as it would not fill out the edge of the blade. A good head is necessary, and large vents and risers at the top edge, to allow some metal to run off and get a sound casting.

To get anywhere near the same pitch in the different blades, the metal must be of the same composition and must be run at the same temperature. The same time must be allowed in each case before easing the mould (at least three hours), and then the blade should be allowed to cool in the mould. The hub may be cast either in dry sand or in a loam mould.

The material used is generally manganese bronze, which is, properly speaking, a brass, being a copper and zinc alloy, with a small addition of ferro-manganese. The manganese bronze used in the propellers of the U. S. S. Charleston, consisted of 100 parts copper, 40 zinc and 2.5 parts manganese. The latter was added to the molten copper and zinc in the form of ferro-manganese containing 20 per cent manganese. The melting was done in a reverberatory furnace.

Wm. H. Cramp & Co. melt all of their material for manganese bronze castings in crucibles, finding that they get much better results.

For the Cincinnati and Raleigh, the hubs were made of 55 parts of copper, 45 of zinc and 5 of ferro-manganese containing 80 per cent of manganese. The blades are of naval bronze, with a small bit of ferro-manganese added.

The blades for the Charleston's propellers were cast in a vertical position, tips of blades down, with a large rising head on flange of blade. The Baltimore's, Philadelphia's and Newark's blades were moulded in loam from a pattern, and were cast on edge, with six pouring gates on the upper edge and a large riser on the flange at root of blade. Sometimes blades may be cast in a nearly horizontal position, but so inclined that the root and palm of the blade lie above the thin tips of the blade.

Question No. 5.—Describe the machine work necessary to put a cylinder casting, as received from foundry, in condition for going in ship.

The casting must be carefully examined for flaws, shrinkage cracks, blow holes, and other imperfections, especially the bore of the cylinder (when there is not a liner), to see that there are no flaws that will not bore out. Sometimes the steam passages are tested by filling them with water. See that the cores for the port nozzles and steam chests have not shifted, and that the valve seats are perfect. When thoroughly cleaned and found sound, the casting is taken to the machine shop, where it is first measured to see that there is metal enough for finishing it to the proper dimensions. It is then lined off, and a flange is planed off to serve as a datum plane. It is then put in the boring mill to be bored in the same position, either vertical or horizontal, in which it is to work. Cylinders of large diameter are generally bored in a vertical position, whether they are to be used in that way or not. The bore of the cylinder is then plumbed up; lines are drawn across the faces of the flanges, and four points are trammeled on these lines to see that the cylinder is not distorted while being secured to the bed, which is then done. The boring bar is placed in position, but before boring, the correct position of the cylinder is verified by attaching a thin batten to the cutter head and letting it travel through the cylinder.

In boring a cylinder it is best not to take more than two cuts, as the metal near the surface as cast is harder than the interior part. If a wearing liner is to be fitted, it does not matter so much about the hardness nor about the perfection of the surface. From three to five cutters are fitted in the boring head, which are set to take successive cuts. They should only leave enough metal to be removed to allow one finishing cut to be taken.

After the first cut is finished, the cylinder should be again trammeled to see if it has sprung at all during the process. It is well to release some of the holding-down bolts for the finishing cut, to make sure that the cylinder is not distorted by being clamped fast, leaving only a sufficient number fast to hold it for the light finishing cut.

If everything is right, take the finishing cut with flat tools, without stopping the cut till the bore of the cylinder is finished. Next counterbore for the travel of the piston and for the boss on the cylinder head. Also bore out for the piston-rod stuffing box. Then set a traverse head on the boring bar and face off the flange for the cylinder head.

It is also well to face off the inside of the cylinder head to the exact shape of the piston, so as to obtain the maximum amount of clearance for the piston, as, when but small clearance is allowed, a hardly perceptible rise on the inner side of the head may destroy all clearance.

If the cylinder has piston valves, the valve chests are next bored out, and the flanges are faced off. Next the casting is taken to the planer, where the flanges and brackets are faced off, the work being laid off from the bore or axis of the cylinder and from the datum plane as established in the beginning. Holes for bolts and studs are drilled and tapped in the flanges, and the studs are fitted in place; core holes are bored out and tapped, and the core plugs are screwed in and secured. If a cylinder liner is to be used, it is turned to size and bored, but not finished, and is then forced into the cylinder barrel. Bolt holes are drilled for securing it, and body bound bolts are put in. The cylinder is then centered on the boring mill, and the finishing cut is taken through the lining.

The valve-seat linings are generally cast solid, but those for the Cincinnati and Raleigh were cast with the ports in them. These are next turned and bored, except the finishing cut. The valve ports are laid out and drilled, and are cut and fitted to size. These linings are then forced or drawn into the valve chests up to a collar, and are secured at the ends by pins tapped half into linings and chests. A finishing cut is then taken with a boring tool.

The stuffing box of a cylinder, having been bored and turned, is fitted to the cylinder, holes for the studs are laid out, drilled and tapped, and the studs are screwed in. The cylinder cover having been turned and faced, both inside and out, and the bolt holes having been drilled, it is fitted in place, and the holes are laid out on the cylinder flange, drilled, tapped, and the studs are screwed in.

Special attention must be paid in boring the cylinders and linings to see that there are no blow holes on the wearing surfaces; wherever holes are discovered they must be probed with a wire to determine their extent.

The steam passages must be carefully examined to see that they have the proper area of cross-section throughout, for it sometimes happens that the area is contracted by an improperly placed rib, by the fins not being cut out, or from the fact that the recess in the cylinder head has not been properly made. The bores of the cylinders and of the valve seats must be accurately measured, must be cylindrical and of uniform diameter throughout, and their axes must be exactly parallel. The bores must be smooth, free from blow and sand holes. The holes for drains, indicators, steam-jacket pipes, etc., are drilled, and are either tapped out to permit pipes to be screwed in, or else they have studs fitted or bolt holes drilled in the flanges.

Question No. 6.—Describe the machine work on a built-up propeller.

The hub, having been cast, cleaned, etc., is turned down on the outside, center lines are marked through the centers of the seatings for the blades, these center lines being circles that pass around the hub in fore and aft planes. The seats for the flanges are bored and faced, and the hub is bored to fit the taper of the shaft accurately, a sheet-iron template being used for this purpose. The hub is then counterbored for about 1 inch for the casing on the shaft. Key ways are cut in the hub to correspond with the key ways in the shaft. The hub must fit the shaft snugly and the keys must drive tight. The flanges or palms of the blades are turned to fit the hub accurately, so that when the blades are bolted down they are firmly seated, and so that as little strain as possible will come on the bolts from the thrust of the screws.

The fair water line piece is fitted to the after end of the hub, and the zinc armature to the forward end, both being secured by manganese bronze bolts.

Test pieces cut from the blades, or cast with them, should show a tough metal.

In turning off the palms of the blades in the boring mill, a guide iron should be secured horizontally to the table, so that the blade at the radius of the center of pressure will rest on it, and then the blade should be so adjusted that it will have the proper lean back (if of such design) and also the right length. A gauge can be made and the edge of the palm marked while the blade is in the boring mill, so that when it is set into place on the hub it can be accurately adjusted to the proper pitch.

After the palms are finished, the work of boring the holes for the bolts is taken up, a jig being made, so that the holes in all the blades are drilled in exactly the same relative positions and of the same size. These holes are made oval to allow for adjustment of pitch. The seatings for the bolt heads or washers are faced at the same time.

The blades are filed and buffed perfectly smooth on both faces, the edges are trued up, chipped and filed to a sharp edge. Covering plates for the bolt recesses are fitted, the securing counter sunk head screws are put in place, and the outer face of the palm of the blade is then finished by filing. The covering plates give an unbroken outline to the surfaces of the hub.

The blades being finished, are fitted into their seatings in the hub, and the pitch marks are verified by using a guide iron at the radius of the center of pressure of the blade. A block fitted with a center punch is put in the holes in the palm, and the centers of the bolt holes in the hub are thus marked; also the outlines of the oval holes in the palm are scribed on the hub, to verify the center punch marks. The holes in the hub for the bolts are then drilled and tapped out, and the manganese or Tobin bronze bolts are fitted. The blades being again put in place, washers are fitted under the heads of the bolts; then the chocks are fitted to fill the oval holes and thus prevent the blade from turning on the hub; after which the bolts are put in and properly set up, and the lock plates are fitted and secured, to prevent the bolts from turning.

The covering plates having been put in place, the propeller is fitted on a mandrel through the hub, and is either swung in a lathe or supported by resting the ends of the mandrel on parallel horizontal surfaces, so as to find out whether the propeller is properly balanced. This supporting mandrel must of course be of uniform diameter throughout its length. If the propeller be found to be improperly balanced, it should be corrected, either by taking away some metal near the tip of a blade or else by adding weight in the recess in the face of the palm of a blade.

After the propeller has been secured on the shaft, the joint at its forward end is made tight by caulking the hub down on the casing of the shaft, after which the fair water line piece on the after end is secured, making a water-tight joint there.

Question No. 7.—Describe the machine work on a crank shaft, connecting rod, or piston rod.

For more complete information relative to the manufacture of crank shafts than is here given, see the Journal of the American Society of Naval Engineers of February, 1891, for a built-up crank shaft, and of August, 1891, for a solid crank shaft.

CRANK SHAFT.—The rough forged crank shaft, either iron or steel, having been received in the machine shop, is lined off for turning, slotting, and planing, care being taken to leave sufficient metal at all points for finishing. The centers at the ends are drilled and the crank shaft is put in the lathe. Weights are secured to the face plate of the lathe to balance the weight of the cranks. The coupling flange and shaft journals are first turned off rough, leaving the diameter 1/4 or 3/8 inch larger than the finished size. The shaft is next taken to the slotter, where the metal between the crank arms is cut out, leaving enough metal for the pins.

The crank arms are next planed to the proper size. Brackets are clamped to the ends of the shaft, so that it may be centered for turning down the crank pins. Struts are fitted between these brackets and the crank arms, and also between the crank arms (the pins of which are not yet to be turned) so as to give stiffness to the shaft.

The pins and faces of the crank arms are turned to their finished size, and the brackets on the ends of the shaft are then taken off.

Chocks are secured between the crank arms to ensure stiffness, and the shaft is placed in the lathe, balance weights being adjusted. The shaft is then turned down to the finished size, and the journals are smoothed.

The several parts of a "built up" crank shaft having been forged, rough turned and planed at the forge, are sent to the machine shop for finishing and assembling. The crank arms are planed to the finished size, the sharp edges being rounded off with a file. The holes for the crank pins are laid out and marked, to facilitate setting the boring bar. Key ways are likewise laid out and slotted.

The crank arms are placed in cast-iron rests secured to the table of the horizontal boring mill, exactly parallel and the proper distance apart, the axes of the crank-pin holes coinciding. The boring bar is now put through the holes previously bored in approximately correct positions, and about 1/8 inch smaller in diameter than the finished size. The holes are now bored to the exact size, one hole being 1/16 inch larger in diameter than the other to allow the pin to pass through easily.

The ends of the crank pin are about one inch larger in diameter than the body of the pin. Key ways are cut in the ends of the pins and the pins are turned to finished size, pieces of hard wood being fitted in the key ways to prevent the tool from catching while turning the pin.

The crank arms are laid on a rest on the floor in the exact position they are to occupy on the shaft. A cage of perforated sheet iron is built around the pin to serve as a heating surface. Charcoal is used as fuel. During the heating process the holes are frequently gauged as to evenness of expansion, and, when they have been expanded uniformly to the proper size, the fire is removed, the holes are carefully wiped out, and the pin is inserted, a temporary key being employed to maintain it in the proper position. Both arms are cooled evenly with water, the intention being that both ends of the pin shall be gripped alike. The holes and key ways for the shafting are now laid out in the crank arms and are then bored in the manner described for the pins. The ends of the shaft are turned to the proper size and the key ways are cut.

Permanent keys are fitted to the crank pins and are driven home, the driving fit being at the sides of the key. The shaft ends of the crank arm, one at a time, are now heated, struts being placed between the crank arms, and a screw jack being provided for moving the shaft back in case it passes too far through the hole. The crank arms are placed either face up or side up, as may be most convenient.

A temporary key is placed in position to guide the shaft to its right position. The key ways are laid out in such a manner that the cranks will stand at the proper angle with each other when the shafts are guided into position as described. Permanent keys are then fitted and driven home, and the shaft, being completely assembled, is put in the lathe and turned off to the finished size. To insure a solid shrinking fit, the crank arm holes for pins and shafts are bored 1/1000 inch to 1/128 inch smaller in diameter than the ends of the pins and shafts, for diameters of 13 to 15 inches.

CONNECTING ROD.—This is forged as near to shape as possible from an ingot of mild steel. The metal between the forks of the crosshead end should be cut out under the hammer and then the forging of that end completed; also holes through the forked or crosshead end and through the crank-pin end should be roughed out under the hammer.

Then the rod is lined off, marked and turned to about 1/8 inch over size. If the forked end has not already been cut out, it must be either drilled, planed and slotted out now, or else this work must all be done on slotter.

Next the rod is put in a boring mill and holes are bored through the ends of the rod for the crank pin and crosshead brasses.

Then the rod is put in a lathe and turned to size and the lathe work finished. Then it is put in a drill press and holes are drilled for the cap bolts at both ends.

The next operation is to put the rod in a planer, where the caps are parted from the rod, after which the brasses can be fitted, set screws put in, and the rod finished.

PISTON ROD.—All work on a piston rod is done on a lathe, except cutting the slots for the keys which secure the piston-rod nuts. These are put in by drilling and then slotting, or by chipping and filing.

The main points to look out for are to see that the rod is accurately turned to size in all its length and that the distance between the faces of the collars is correct. The wearing surface of the rod should be ground perfectly true.

Question No. 8.—Describe the manufacture of any large forging of steel or iron.

For tests of material and inspection, see the most recent specifications.

A solid iron crank shaft is forged by piling fagots of selected scrap iron or billets, heating them in a reverberatory furnace and welding them together under the steam hammer, commencing at the porter bar and gradually extending the shaft. The crank arms and pins are built up as solid masses of metal, placed at the proper angle with each other. The shaft is forged to such a size that all rough spots will be turned or planed off when the shaft is brought to the finished size.

Solid steel crank shafts are made from ingots of circular, octagonal, or elliptical section. The ingot is bottom cast, in a vertical position, and is of uniform section throughout its length, with a long rising head of large diameter, which serves for the attachment of the porter bar. The diameter of the ingot must be larger than the total length of the cranks. The ingot, being heated to the proper temperature, is brought under the steam hammer and a rectangular piece of metal is cut out between the cranks; the remaining metal, which forms the length of shaft between the two cranks, is hammered out. After reheating to a high temperature, the shaft is twisted so that the masses of metal forming the crank arms stand at the proper angle with each other. This twisting is accomplished either by light blows of the steam hammer, or by means of an hydraulic press. Triangular portions of the ingot are cut out to define the outer limits of the cranks and of the shaft coupling, and the cranks are brought down to the proper size under the hammer. The angle of the cranks is finally verified and inaccuracies are corrected.

The ingots for steel shafts must be made long enough to reject ends, especially upper ends, which show piping or blow holes. Recent specifications provide that at least 30 per cent of the weight of the ingot is to be cut off and rejected.

The dimensions of the ingot should be sufficient to allow considerable work to be done on every part of the shaft in forging it down to size. This is difficult to obtain for solid crank shafts.

Nearly all steel shafts are now made with an axial hole, either bored in the solid shaft or forged. In the latter case, the forging is done by powerful hydraulic machinery, a mandrel being forced through the hole formed in the ingot. The axial hole must be carefully examined for cracks and flaws. While the shaft is being turned, a watch must be kept for flaws, which in iron shafts are often due to imperfect welding. Test pieces are cut from the ends of steel shafts, and from the portions slotted out from between the crank arms, which pieces are subjected to tensile, bending and quenching tests.

Chemical analyses are also made from specimens of the shaft, to ascertain the percentage of carbon, phosphorus and sulphur.

The inspector must satisfy himself that these provisions of the specifications are strictly adhered to.

A good indication of the character of the metal is afforded by the manner in which it works in the lathe.

Too much care cannot be taken to have the holes in the crank arms, on which the trueness of the shaft principally depends, laid out with the utmost accuracy.

The "Whitworth" process is to apply a pressure of from 6 to 20 tons per square inch to the fluid metal, the moulds being steel cylinders lined with cast-iron bars. These lining bars are pierced with holes and covered with ganister, and are made sufficiently strong to stand the great pressure.

If the shaft is to be hollow, a core made of cast-iron bars, pierced with holes and covered with ganister, is put into the mould, this core being made so that on removing one bar the others can be easily removed. The great pressure drives out nearly all the confined gases and reduces the length of the ingot about 12.5 per cent.

These shafts have a tensile strength of 90,000 pounds per square inch, with an elongation of 32 per cent.

The ingot is forged over a mandrel by hydraulic pressure.

Question No. 9.—Describe the work of building a large boiler.

The plates and other material are inspected at the place of manufacture by an inspector who makes all the tests for quality, etc., according to the specifications.

When delivered at the boiler shop, the plates usually undergo another inspection for surface defects, thickness and weight. All steel plates not to be worked in the fire are placed in a pickling bath containing about 5 per cent of sulphuric or hydrochloric acid in water, in order to remove the mill scale. After leaving them in the bath for about six hours, they are scrubbed with hickory brooms, washed off, and are then put in a tank containing lime water, to neutralize the acid.

Work is begun on the flange plates, which are marked after being laid off, and, if necessary, they sheared nearly to size and then flanged.

The shell plates of boilers are marked and planed to proper dimensions, the caulking edges being planed and beveled. The rivet holes of circumferential joints of outside courses and of joints for the heads on end courses are marked, and the plates are then rolled to the proper radius. Usually either a four-roll machine is used for a distance of 12 inches or 15 inches from the end of the plate, or else this part of the shell is formed by the hydraulic flanging machine in a former.

The longitudinal butt straps are likewise planed and bent to shape in a former, and the rivet holes in the butt straps outside of the shell are drilled. The separate courses are then fitted together and the butt straps are placed.

The several courses are now fitted together very carefully and secured by tack bolts, a few holes of smaller diameter than rivet holes having been drilled for this purpose through the sheets. Thus fitted together, the shell is brought to the drilling machine, and the rivet holes are drilled, using the holes previously drilled in butt straps, etc., for guides. Sometimes all the holes in the circumferential seams of outer courses are drilled before the sheet is bent, but this is not the best practice.

Holes for stay bolts and other fastenings are likewise laid off and drilled. The plates are next taken apart and the burrs taken off, so that plates may lie close together.

In flanging, formers for the different parts should be made so that the work may be done in such a way as to make the parts fit well.

The flanges for the head sheets are marked off by prick punch marks on the line of the bend, and are then heated to a bright red heat, after which the flanges are turned by an hydraulic flanging machine. Allowance for shrinkage is made, especially in turning the flanges to which the furnaces are secured. These latter are made by using an inside former, the work being done by one stroke of the machine.

After flanging, the sheets are put in an annealing furnace, heated to a red heat, brought out on cast-iron bed plates, straightened, and allowed to cool gradually.

They should then be pickled to clean off the scale of black oxide.

The flanges are planed or chipped true, the heads are fitted in the shells, the rivet holes laid out and drilled around the flanges and in the cross seam where the upper head is joined to the tube sheet.

The furnaces, being corrugated, have been received ready made from the manufacturer. The back tube sheet and back connection sheets, after being flanged and annealed, are fitted together and to the furnaces, and all are secured together by tack bolts. They are then taken to the drilling machine and rivet holes are drilled, after which they are then taken apart and burrs cleaned off.

The center lines of the furnaces are marked on the back tube sheets, and when they are taken apart the tube holes are laid off and drilled with special cutters, after which the sheets are assembled and riveted together. The furnaces having been fitted in the heads or in the front tube sheets, the centers are marked and, the flue being removed, the tube holes are laid off and drilled. Manholes are cut and strengthening rings are fitted and riveted to the head sheets. Corners of flanges where more than two laps meet are drawn down by hand.

The angle irons are riveted to the top and to the bottom of the back connections, then the seams on outside and inside of the back connections are caulked. The seams of the shell, after being riveted, are caulked, the inside seams being done first to hurry the work (hydraulic riveting is used when practicable). The furnaces and back connections are now put into the shell, and are blocked up and wedged into position. The front heads are fitted in the shell, and are first secured by tack bolts and then riveted. The shell has been fitted close to the flanges, which are drawn together by bolts, the operation being assisted by a heavy hammer. Where necessary, local heat is applied to bring the shell closer to the flanges.

The parallelism of the tube sheets is next verified, and a few tubes are put in to insure coincidence of the holes in tube sheets.

The holes are drilled through the furnace flanges in the front head, and the furnaces are riveted in place.

The holes for the stay bolts are now drilled in the back connection sheets, using the holes in the shell plate as guides. The holes are tapped out with a long tap, reached through the shell and the back connection plates. Screw stay bolts are screwed in, and the nuts are put on with stiff putty in counter sinks on faces of nuts. Before putting on these nuts, the shell is caulked around the stay bolts to make them tighter.

Gusset plates and other braces to the top of the back connections are secured. The holes are then drilled for the screw stays between combustion chambers (if not previously done) and those screw stays are fitted and secured. The washers having been riveted to the heads, the braces are put in and secured by inside and outside nuts.

Putty is used to make tight joints of inside nuts. These having been adjusted and screwed up, the outside nuts are put on, grommets are put in counter bores on their faces, and they are set up hard, using a tackle on the wrench.

The tubes having been pickled, are ready for putting in, stay tubes first. Taps for both tube sheets are on one long rod, adjusted so as to make a continuous thread. The holes in the front tube sheets are large enough to let the tap for the back tube sheet pass through, tubes being swelled more on front than on back ends. The thread is cut first in the back tube sheet. The tap then continues in a plain thread while the front tube hole is being tapped out with a taper tap.

Tubes having threads cut on them are screwed in until they fit perfectly tight in the front tube sheet; the back ends of the tubes are expanded and beaded over in a recess formed in the tube sheet. A ferrule should be driven in the back end to protect the tube ends when forced draft is used.

Next the ordinary tubes are put in and expanded. These tubes must be swedged out at both ends, but slightly more in front, so that the back end passes freely through the front tube sheet. Tubes are expanded and beaded over, and their back ends are supposed to be protected by a cast-iron ring fitting tight in a recess in the back head, though a ferrule would be far better.

Manhole and hand hole plates are stamped out of plate steel, the bolts, nuts and dogs are fitted, after which the plates should be carefully fitted by chipping, filing and scraping to their places in the boiler. Each one should be carefully marked, so that it can always be put in its proper position, thus saving the trouble of leaky joints.

All the seams having been caulked, the boiler is ready for applying the test pressure, which, in naval practice, is equal to one and a half times the working pressure, and which is applied by filling the boiler with water, and then building light wood fires in the furnaces, gradually heating the water up to about 150°. A part of the cold water is allowed to run off in order to regulate the pressure, so that it shall not go above 50 or 100 pounds till the water is well warmed throughout the boiler.

The inspector has to be very vigilant in the inspection of the plates, watching not only for original defects but for flaws or cracks which may develop in working the sheets. *No steel plate should be worked, flanged or hammered at a black heat or at a blue heat, as it is sometimes called. It is better to work the metal cold.* No drifting of rivet holes must be allowed. If the holes do not come perfectly fair, they must be reamed and a larger rivet used. All holes for hand-driven rivets should be counter sunk at least 5/16 of an inch.

Steel braces must not be welded. The ends of braces are upset for the screw head. The tubes must fit the holes snugly. After expanding and beading over the tube ends, there must be no signs of cracking. The ends of the tubes that are to be expanded must be annealed. Sheets must lie close, metal to metal, before being riveted. During the application of the test pressure, all parts of the boiler must be examined. There must be no sign of bulging, and all leaks must be made tight by caulking. Dutchmen should not be allowed in the boilers.

After the test, every seam and rivet being tight, the holes are cut for the main nozzles and for all valves, and the nozzles are carefully fitted to the shell, each joint being filed and scraped to a good joint.

The furnace fronts are also fitted, and work is begun on the front connections and uptakes, a large portion of which work can be done more expeditiously and economically while the boilers are in the shop than after they are placed in the vessel.

All this being done, the boiler is painted, the inside cleaned out and dried, the tubes and connections of furnaces are oiled with crude petroleum, and the boiler is ready to be put in the ship.

Question No. 10.—Describe the work of running lines in a ship and erecting her engines in place.

(This description is of the method employed aboard the Cincinnati.)

The engine drawings give the positions of the centers of the shafts at the H. P. cylinders and in the middle of the length of the stern brackets, above the base line and outboard of the center line of the ship.

These dimensions are checked off on the mould loft floor, and similar dimensions are taken for points on the athwartship bulkhead about 3-1/2 feet forward of the engines, and for the after end of the stern brackets.

After the stern tubes and brackets are secured in place and all riveting is completed around them, the constructor has the base line laid off on the outside of the hull, and from this base line and the center line of the keel are determined the shaft line centers on the after side of the stern brackets and on the bulkhead forward of the engines. This is done by means of straight edges, levels, rules and plumb lines, the forward points being obtained by working up through openings in the hull for two of the outboard valves in the forward part of the engine rooms.

A 3/32-inch diameter hole is drilled through the bulkhead at the forward end of each line and a composition bushing is fitted to it, this bushing having a 1/64-inch diameter hole in its center.

On the after side of the stern brackets, circles are struck from the centers found and marked on the steel castings.

The distance between these end points for the Cincinnati is 115 feet 6 inches, the length of the stern tube being about 34 feet 10 inches, and from the after end of the stern tube to forward end of the stern bracket is about 27 feet 8 inches.

A steel wire is next stretched through these end points from the center point in the bulkhead to the wooden trestle work abaft the stern brackets, which wire is kept in place for several days in order to determine what effect the sun has in warping the hull. Pointers are attached to the brackets and to the after ends of the stern tubes, and measurements are taken from them on a wooden platform built up from the ground.

Observations made at 5 A. M. and 6.30 P. M., on a bright day, gave the same positions for the stern tubes and brackets, and at 8 A. M. the change was hardly perceptible.

Wherever a center point is to be established, a piece of pine board is secured and, at the center given by the wire, a 1-inch hole is bored.

The telescope is first secured and centered at the after end of the stern strut, and then adjusted so that the cross hairs intersect on the 1/64 hole in the bulkhead forward of the engines, when it is clamped fast by means of the adjusting screws: the target (uncovered) is held in front of the 1-inch hole in the board center, and a light held behind the board brings the crosshead lines distinctly into view. The telescope is then focused on the target, and a minute's work suffices to center the target so that the telescope cross hairs will exactly cover the cross lines on the target. The target is then secured in place by thumb tacks. Another sight is taken to see that it has not been moved, and, if correct, the cover is slipped on and a pair of trammels used to describe a circle from this center on the previously chalked surface of the steel castings of the stern tube or engine framing. Center points are thus established at each end of the stern tubes.

For the engine seatings, a box is made to fit in the pocket of the framing, where it is wedged fast, so that a 1-inch vertical slot through the top of the box is at the approximate center given by the wire, after which the target is used to give the exact center. Centers are thus located for both ends of each of the four bed plates of each engine, and points are established on the seatings.

The work of establishing these points is done either before or after working hours, when there is no appreciable movement of the hull.

Horizontal and vertical lines are also established at each end of the engine seatings by means of straight edges, levels and plumb lines, for use in placing the bed plates and erecting the engines.

Before the boring bar is placed in position, a line is stretched through the tubes and exactly centered at the ends and in the middle. The tube is then carefully calipered to make sure that there is sufficient metal to bore out for the seatings. In the starboard tube of the Cincinnati it was found necessary to move center line of the shaft down and inboard 1/16 inch, after which all the intermediate center points were again established.

Before the vessel is launched, the stern tube and screw shafts and the stern tube shaft stuffing boxes should be put in place; also all outboard valves, which last are secured against accident by putting blank flanges on them, either on the outside of ship or over the inner nozzles.

A template of the engine bed plates should be made and tried on the engine seatings to see that they have been properly built to shape and location, and from this template the position of the centers of the H. P. cylinders are located on the seatings, the template being shifted a little, if necessary, to give better locations for the holding-down bolts, etc.

After the vessel is launched, the bed plates are sent on board and placed, either by the centers marked on the seatings, or by a line stretched from the shaft axis center point in the forward bulkhead to the center point of the stern tube shaft. After the bed plates have been bolted securely together, the center line of the H. P. cylinder is adjusted by the marks on the seatings giving the fore and aft position of the bed plates. The bed plates are adjusted in height by jack screws fitted in them, so as to raise them the proper height above the seatings, which are generally built 1 inch low to allow of adjustment of bed plates by means of horse shoes around the holding-down bolts or by wedges between the bed plates and seatings.

The centers for the holding-down bolts are marked through the engine seatings, and the bed plates, having been raised about 15 inches and blocked up, form a good strut from which to drill the holes in the seatings. These are drilled a trifle small to allow of being reamed after the boilers, etc., are in the ship and the engine correctly lined.

The thrust shaft and bearing can also be put in the ship and lined up, by bolting the thrust shaft hard and fast to the forward coupling of the stern tube shaft, from which point we must finally work, as the weight of the boilers, etc., that are later placed in the ship, or even the launching of the ship will generally make some change in the lines run while the ship is on the stocks.

The thrust bearing being placed in line as above, the centers for the holding-down bolts are marked, the thrust bearing is raised and blocked up and the holes for its holding-down bolts are drilled, the holding-down bolts are fitted, and the sole plate is secured in place. The thrust block can afterwards be exactly adjusted by means of the longitudinal and thwartship keys.

When all the holes for the engine bed plate holding-down bolts (or such of them as cannot be drilled after the bed plates and engines are in place) are drilled, and when pockets are cut where necessary for nuts under the seatings, the bed plates are lowered into place and lined up for the seatings of cylinder the columns by longitudinal straight edges over planed surfaces, by means of the vertical and horizontal lines run while the ship was on the stocks, and by using the center lines run through the bearings of the crank shaft. This being done, and the bed plates being well supported by the jack screws or wedges driven between the bed plates and seatings, the crank shafts are put on board in their bearings. The couplings should come perfectly fair with one another and with the coupling of the thrust shaft.

The condensers, air pumps, etc., that belong abaft the main engines should be put into place, lined up, and secured to their seatings before any parts of the main engines above the bed plates are put in, as otherwise the parts of the machinery secured under the main engine hatch would prevent any other large piece of machinery from being lowered into the engine room.

The engine columns or guides are next put in, and, the boilers having been placed in their places in the ship, the lines used in erecting the engines in the shop can be again run and the bed plates placed in their exact positions by working from the coupling of the stern tube shaft (seeing that all couplings come perfectly fair) and from the horizontal and vertical lines in the ship, to see that the bed plate and columns or main guides are in proper position.

This being done, the rest of the holes can be drilled for the holding-down bolts, all holes reamed through the bed plates and seatings, the horse shoes around the bolts can be accurately fitted and the holding-down bolts put in place and secured. Other parts of the engines are now put on board ship and secured in position as is most convenient.

The connecting rods and cross heads are next put in place, then the reversing engine and shafts are lowered into the engine room and stowed away; also all pumps, the auxiliary condenser, and other large pieces of the machinery or fittings. After which the cylinders are put in place as circumstances may direct.

The cylinders being secured in place, the final lines are run, using the center or line marks made in the shop while erecting the engines on a solid foundation.

The crank shafts are revolved to see that they have a perfect bearing in their brasses and that the couplings are perfectly fair, one with the other, the thrust shaft is revolved to see that it is in line, and then the line of shafting is coupled up in its proper position.

After this the piston rods and pistons are put in, and all other work is erected as it was in the shop.

The piping is put on the engines, and other piping, having been made, but left with loose flanges, is taken on board ship and fitted and the position of the flanges marked. It is then taken to the shop and the flanges are brazed or riveted in place.

Question No. 11.—Describe the work of boring out and fitting stern tubes and shaft struts.

These having been secured in place and all riveting finished around them, and the lines (as given in question 10) having been run, and the center of the shaft marked on the after side of the stern strut and on the forward and after ends of the stern tube, boring out can be commenced.

The stage work for the support of the boring bar can be built up with heavy timbers from the ground; or a better method, if it is possible to use it, is to have the boring bar accurately supported from the hull, so as to partake of the movements thereof.

The boring bar should be a hollow one and perfectly true. The method employed in boring out the stern tubes and struts of the Cincinnati was as follows:

The boring bar used was hollow and 24 feet 9 inches in length and, therefore, had to be shifted in order to bore out the seatings for the three bushings in the stern tube.

In boring out the stern brackets, the after end of the bar was set by the circle described on the after face of the bracket and the telescope was placed in the after end of the bar, a plate being made of such diameter that it exactly fitted into a recess in the bar, thus centering the telescope cross hairs.

At the other end of the bar in a similar recess, was fitted a ring, across which were stretched two fine horse hairs, intersecting at the center of the bar, and then the forward end of the bar was moved till the telescope cross hairs and those in the forward end of the bar were in line with the 1/64-inch hole in the bulkhead forward of the engine room. The boring bar having been thus located, its end bearings were secured and the center bearing adjusted so as to compensate for the sag of the bar, which had been previously determined in the shop.

The movements of the hull were plainly shown while boring out the stern brackets by the cuts taken just before and after the dinner hour, the boring bar being supported on a wooden frame work built up from the ground.

In boring out the stern tubes, the bar is first placed in the after end of the bar set by means of the circle previously established on the after face of the tube; the telescope and cross hairs are again placed in the bar and the forward end of the bar is adjusted by means of six bolts working in the shell of the stern tube, just forward of the seating for the middle bushing and working against a composition sleeve in which the boring bar revolves.

The sag of the bar is taken up at its middle by another sleeve, which is also adjusted by bolts fitted through the shell of the stern tube.

After boring out the seatings for the after and middle bushings in the stern tube, the bar is slipped through the tube till its forward end projects beyond the forward end of the tube, where it is centered by the circle struck on the forward face of the tube, the after end being centered by a bushing fitting the seating already bored out for the middle of length.

This way of boring out the stern tubes and struts is better (though more expensive) than having them bored out in the shop, for in the latter method they are liable to be thrown a little out of line while being secured in their place to the vessel.

If they are to be bored out in the shop, they are first fitted in place and all holes for rivets and bolts to secure them should be drilled and reamed and the tubes and struts should be securely held in place. The center line is run through them and the centers are located on their ends by scribing circles (larger than they are to be bored out) from the shaft center, to serve as guides to bore them out when they have been removed to the shop.

The bushings for the shaft bearings and the fair water line pieces are all machined and bored out in the shop.

The parts are put in place and centers marked for the studs, which are screwed into the steel castings to secure them.

The middle bushing of the stern tube is connected to the after bushing by two composition sleeves, and when, screwed together, these are all drawn or shoved into the stern tube. When they are in place four set bolts are tapped into the stern tube casting and are let into the middle bushing to prevent its turning with the shaft. The forward bushing in the stern tube and the ones in the brackets are in halves, to make them more easily removable.

Question No. 12.—Describe the details of building a condenser.

The modern condenser is generally made cylindrical and cast of composition, for naval work using the proportion of 88 C—10 Z—2 T. Usually the body is cast in three sections, the middle section carrying all the nozzles.

At the New York navy yard the sections are moulded in loam, the process for the middle section being the same as for a steam cylinder. A dummy cylinder is first swept up and the pattern for the different nozzles and flanges fitted in place, and then a loam mould is built around these (for the large exhaust nozzles a skeleton pattern is used, the thickness of the ribs and other pieces of the pattern giving the thickness of the metal). The loam work is first built up flush with the inner surface of the skeleton pattern to serve as the core, then the thickness is fitted in with damp moulding sand and smoothed off flush with the outside surface and then used with the dummy for building up the main mould. Drawbacks are made where necessary for removing the pattern or taking the mould apart. Afterwards the dummy is cleared away, the patterns removed, the surface of the mould smoothed and blackened and put in the oven and baked. The cores for all sections are swept up.

The end sections, being entirely cylindrical, are swept up, the only patterns used being those for the flanges by which the condenser is attached to the hull.

The middle section is cast about 1/2 inch thick, the mould having about 3/8-inch space at bottom, increasing to a little less than 1/2 inch at the top. All parts are cast with the axes in a vertical position. The end sections are made 1/4 inch to 5/16 inch thick, the mould having 3/16-inch space at bottom, the pressure of the metal gaining the other 1/8 inch.

In building the cores, three relieving bars are built in so as to provide for the quick relieving of the core, so that the metal solidifying and shrinking shall not be subjected to any tensile strain while still hot and in a rotten state, when the flanges would easily be cracked away.

As soon as the metal is poured a man goes into the center of the core and with a bar removes the three relieving bars, and by that time, the metal having solidified, the brick work of the core may be broken away, allowing free shrinkage. A pit is provided in the center of the core for the loose bricks, etc., to fall into. The brick work of the mould and of the main nozzle is also broken away.

Quick work is necessary. The core is eased inside of seven minutes after the metal begins to run into the mould, and the outside is usually stripped within 15 or 20 minutes after the metal has been poured. To prevent the metal from chilling while being poured into the 1/4-inch space, it is better to have the mould warmed by light fires hung inside the core.

After being cleaned and having the fins chipped off (it should also be washed with a pickle of muriatic acid, 17 of water to one of acid) the piece is sent to the machine shop, where it is measured to see if it will turn up correctly. If right, it is subjected to a hydrostatic pressure of 30 pounds per gauge, and if no flaws develop it is put into a large lathe and the ends are turned to length. The joints and the flanges for joining the sections together and to the tube sheets are then faced off.

The middle section is then put on the planer and all the flanges and nozzles are planed to the proper thickness and angle, or else are dressed off by hand. Afterwards all the holes for the bolts are drilled, and those for the studs are tapped out.

The main points in regard to the manufacture of condenser tube sheets are to see that the tube holes and stuffing boxes for the tubes are all cored out to about the right size, and that afterwards a reamed fitting both parts is ~~tapp~~put ed in and that all reaming is done in one operation. Then the stuffing box is tapped out for the screw gland.

The three sections are screwed together by Tobin bronze bolts, the joint being made with lead putty. The sections should have lips fitting into recesses on the adjoining part to secure tightness and stiffness.

The tube sheets are secured to the end sections by means of collar studs, the flanges being flush with each other. These studs also serve to secure the heads.

The tube sheets are in pairs, so that the tube holes match. They are carefully lined in place, so that the tubes shall go in fair. Then the bolt holes are marked from those already drilled in one of the match flanges, generally the tube sheet, and the sheets are taken away and these holes drilled.

The interior of the condenser is then fitted up with a scattering or deflecting plate supported by angles, and hangers are fitted directly under the main exhaust nozzle to prevent the steam striking directly on the tubes, and forcing it towards the end of the condenser. Two supporting plates for the tubes are put in, being each drilled to correspond with a little more than one-half of the tube sheets. These are placed about 2 inches apart, near the centers of length of the condenser, and are secured by lugs cast in them and bolted to the body of the middle section of the condenser. These plates serve to give each tube a support near its center and prevent rattling and sagging of the tubes. Another deflecting plate is put in below the top scattering plate, but it may possibly be useless except so far as it serves to stiffen the supporting plates, which are secured to its edges and which do not need other special stiffening.

All parts of the condenser are of composition except the rivets, which are of copper.

The above parts being finished, the tube sheets are secured in place and stiffened by four stay rods and socket tubes. These rods are of Tobin bronze 3/4 inch diameter.

A board is bolted over one end of the condenser to prevent the tubes being driven out while being packed and the tubes are packed, first one end, then the other.

A vulcanized fiber grommet should first be placed in the stuffing box. Then a cotton tape (like a corset lacing) about 50 inches long, which has been waxed, is wound around a mandrel and driven into the stuffing box with a tool like a wad cutter. Then another grommet should be put in, and finally the screw gland inserted and set up. These glands have part of their back edges flanged inward to prevent the tube from crawling.

The condenser heads are swept up and patterns are used for the flanges for securing the injection and delivery valves or pipes.

Each head has four small bonnets, so that the ends of the tubes may be inspected and slight repairs made without removing the large head. Air cocks are fitted at the highest points of the heads in the salt water space.

The middle section, besides the main exhaust nozzles and air pump suctions, has also a nozzle for a bleeder pipe, one for soda injection, one for admitting steam at the bottom for boiling out the condenser, and also a man hole on the back of the main exhaust nozzle to allow examination of the interior of the condenser.

The heads are faced off in a lathe, then the faces for the valves and small bonnets are faced off on the planer, then the holes for bolts and studs are marked off, drilled and tapped. Also the holes for the stay bolts are tapped into the tube sheets, staying the center of the heads.

The condensers for the Cincinnati and Raleigh built in this way are 59-1/4 inches inside diameter, 13 feet 5-1/2 inches length over all, and have 6990 square feet of condensing surface, there being 3715 5/8-tubes with exposed lengths of 11 feet 6 inches, or 11 feet 8 inches total lengths.

Question No. 13.—Give an outline of the method of fitting and erecting steam and exhaust piping, with a statement of the precautions that should be observed.

In fitting piping, especially of large size, the pipes should be carefully fitted to place, without springing them. For this purpose it is better to leave the main flange loose until the pipe can be put in position, when the flanges should be correctly placed and marked. They can then be riveted, brazed or burnt in, and afterwards the pipes can be put in position again and the bolt holes in the flanges marked and drilled.

Before being secured in place, the pipes should be tested to see if they have the necessary strength, and to make sure that all seams and flanges are perfectly tight.

For naval work the flanges of large pipes are riveted on, and the pipe itself flanges over into a recess in the face of the flange. Either spelter or solder is run in, according to the pressures and temperatures to which they are to be subjected.

For the pipes around the engines, where they are generally short and stiff, slip or expansion joints should be provided for each section of pipe between fixed points, to allow for contraction and expansion, care being taken that the sleeve of the slip joint cannot pull out of the stuffing box. This is prevented by four or more studs fitted into lugs on the stuffing box flange and passing freely through lugs on the flange of the sleeves and having nuts on the ends of the studs.

Slip joints should also be provided for long stretches of pipe above 4 or 5 inches in diameter, unless the pipes have bends in them, with space to move in during expansion and contraction.

In passing through a water-tight bulkhead, the pipe is fitted to a slip joint, the stuffing box of which is so fitted that it has a small movement in any direction along the bulkhead.

The pipes must be well supported so that they will not sag by their own weight, which might start the joints leaking.

Drains must be fitted to thoroughly clear the pipes of water and prevent damage by water ramming or freezing in pockets. These drain valves and pipes should be large enough to clear quickly. Drains from steam pipes should lead to traps, thence to a feed tank, and those from the exhaust pipes should lead to tanks or condensers.

Care must be taken that the pipes do not work against anything that could wear through the copper.

For short elbows or pieces having several nozzles, composition castings are sometimes used. The Bureau of Steam Engineering requires 1 square inch of drain pipe area for each 8000 cubic inches of steam pipe, but no drain pipe can be less than 3/4 inch diameter. Special care must be taken in draining pipes between stop valves, and all low sections of pipe where the water might settle.

Subject No. 5.—Strength of Materials, Metallurgy and Shipbuilding.

(The use of works of reference is permitted in solving problems.)

Question No. 1.—Work out the thickness of shell, detail of riveting, thickness of furnaces, diameter of braces in steam spaces and size and spacing of stays for a cylindrical boiler of given diameter and steam pressure.

Work out thickness of shell, detail of riveting, thickness of furnaces, diameter of braces in steam space, size and spacing of stays for a cylindrical boiler of given diameter and steam pressure, where $P =$ gauge pressure and $D =$ diameter of boiler (mean diameter).

FOR THICKNESS OF SHELL: assume strength of joint 80 per cent of plate and steel 60,000 pounds tensile strength.

$P = \frac{2Kt}{D}$. Allow 1/16″ for corrosion (Seaton allows 1/8″).

$K =$ safe working strain on metal, which, with a factor of safety of 4-1/2, becomes;

$$K = \frac{60{,}000 \times .80}{4\text{-}1/2},$$

therefore $t = \frac{DP}{2 \times K}$ plus $\frac{1}{16} = \frac{DP \times 4\text{-}1/2}{60{,}000 \times .80 \times 2}$ plus $\frac{1}{16} =$ thickness of shell.

RIVETING.—Use double butt straps, treble riveted, of the following form:

The outside rows of rivets are used as backers to the inside row and by having the large space, increase the proportional strength of the plate, which must tear through them first.

The strength of the plate and rivet must be the same, or as nearly so as possible.

The most important point is to have a joint that can be caulked. The idea is to space outside rivets near enough to make a good joint and far enough to give strength to the sheet between them, making the strap at least 5/8 of the thickness of the shell.

Double shear equals 1.75 × single shear, which is (say) 23/28 tensile strength. Assume rivet strength to be equal to .80 of sheet. Space rivets 8 inches apart, which gives us five rivets in each space.

We have:

$$\frac{t \times 8 \times 60{,}000 \times .8}{5} = a \times 1.75 \times 23/28 \times 60{,}000$$

where $a =$ area of rivet; $t =$ thickness of sheets.

$$\frac{t \times 8 \times .8}{5} = a \times 1.75 \times 23/28 \text{ or } a = \frac{t \times 8 \times .8 \times 28}{5 \times 1.75 \times 23}.$$

In other words, the area of the rivet is equal to thickness of sheet multiplied by distance of spacing of outer row × per cent of joint, divided by number of rivets in the space × strength due to double shear.

The strength of the sheet is weakened by taking $\frac{a}{.7854}$ out of 8 inches leaving $8 - \frac{a}{.7854}$.

Therefore $8 : 8 - \frac{a}{.7854} = 100 : x$.

The spacing of the inside rivets is 1/2 that of the outside and they may be staggered or chain of equal strength.—*Board of Trade Rules* (Seaton).

FOR THICKNESS OF FURNACE of cylindrical boiler, we have, if made of iron welded or butt strapped:

$$\frac{90{,}000 \times t^2 \text{ in inches}}{(\text{Length in feet} + 1) \times \text{outside diameter of furnace in inches}} =$$

P = working pressure, if that does not exceed $\frac{8000 \times t \text{ in inches}}{\text{outside diam. in ins.}}$, which limits the crushing stress on material to 4000 pounds.

If made with rings, the length should be taken between rings. If corrugated, with plain parts at end not exceeding 6 inches and plates not less than 5/16 inches, the working pressure should not exceed

$$\frac{9000 \times t \text{ in inches}}{\text{Mean diam. in inches}}.$$

If the furnaces be made of steel, corrugated, we have $\frac{14{,}000 \times T}{D}$ = working pressure. T = thickness in inches; D = outside diameter in inches.

Corrugated furnaces made of steel should be rolled and should not have flat surfaces of more than six inches in length of furnaces (Seaton).

BRACING.—The diameter of the braces in the steam space (Seaton) is given by $\frac{C \times (T + 1)^2}{S - 6} = P$ = working pressure,

where T = thickness of plates in 1/16ths of inch.

S = surface supported in square inches.

C = constant according to circumstances; as follows: C = 160 when plates are not exposed to the impact of heat or flame.

The stays are fitted with nuts, and with doubling plates of same thickness as plates they cover, and of a diameter not less than 2/3 pitch of stays.

$C = 150$ as above, except for stays fitted with nuts and washers (outside) having a diameter of at least 2/3 the pitch of the stays and of equal thickness to the plates they cover, etc.

SPACING OF STAYS.—

$$\frac{1.1 \times C\,(T + 1)}{S - 6} = P = \text{working pressure.}$$

The stays are screwed into the plates and riveted. If nuts are used, 1.1 becomes 1.25, or $\frac{1.25 \times C\,(T + 1)}{S - 6} = P$.

In the back connections, $C = 90$; in outside stays with washers under the nuts, $C = 150$.

The diameter of the screw stays is found from the formula

$$\text{area of stay} = \frac{S \times P}{6000}.$$

6000 pounds being considered the maximum strain per square inch of section that should be put on such stays.

The spacing of stays in both connections, and wherever heat strikes them, is generally 7 inches from center to center.

Question No. 2.—Design a crank shaft for engines of a given size, from data furnished.

$D = 4.24 \sqrt[3]{\frac{\text{I. H. P.}}{n}}$, where n = number of revolutions per minute, and I. H. P. = horse-power.

The bearings of the crank shaft should not be subjected to more than 500 lbs. pressure per sq. in. of projected area. Pressure per sq. in. × velocity in ft. per min. must not exceed 9000;

$$\frac{\text{Area of H. P. cyl.} \times \text{boiler pressure}}{500} = \text{projected area.}$$

$$\frac{\text{Projected area}}{\text{Diam. of shaft}} = \text{length of bearing.}$$

The crank pin should be of same diameter or a little larger than the shaft (say 1 inch) and the pressure should not exceed 700 lbs. per sq. in. of projected area, and pressure per sq. in. × velocity in ft. per min. should not exceed 15,000.

THE CRANK ARMS should be 0.7 to 0.8 the diameter of the shaft journals.

Let P = load on piston; L = length of pin plus thickness of crank arm; and a = width and b = thickness of the arm.

Bending moment $= \frac{P \times L}{2}$.

a $=$ 0.7 or 0.8 diameter of shaft.

$b = \frac{3P \times L}{2\,a^2 f}$ where $f = 8000$ (Seaton).

When the shaft has a hole through it, the diameter of said hole should equal the half diameter of the shaft.

The line shaft should be 1/4 inch smaller in diameter than the crank shaft.

The propeller shaft (outside of the ship and in the stern bearing) is made the same diameter as the crank shaft.

THRUST BEARINGS.—The pressure on the bearing surface must not exceed 50 pounds per square inch.

Thrust in lbs. $= \frac{\text{I.H.P.} \times 217}{S}$, where S is the speed in knots per hour; this divided by 50 $=$ area of collars.

For diameter of collars on thrust shaft,

$$\text{the mean normal thrust} = P = \frac{\text{I. H. P.} \times 217}{S}.$$

If $D =$ diameter of collars, $d =$ diameter of shaft and $n =$ number of collars; then

$$P = 50\pi\left(\frac{D^2 - d^2}{4}\right)n,$$

therefore

$$D = \sqrt{d^2 + \frac{P}{39n}},$$

If $T =$ thickness of collars, then for strength

$$T = \frac{P}{n \times \pi d \times 1000} = \frac{P}{3142\,d\,n}.$$

In practice, $T = 0.4\ (D - d)$.

Space between collars if solid brass $= 0.4\ (D - d)$.

If of cast-iron faced with brass or white metal $= .75\ (D - d)$.

Let $T =$ twisting moment on coupling.

$t =$ thickness of coupling; $r =$ distance from center of shaft subject to a twisting moment T.

$$T = 2\pi\, rtf \times r = 2\pi\, r^2 tf;$$

i. e., $t = \frac{T}{2\pi r^2 f}$. $f =$ strain per sq. in. on section at distance r.

t should be about 0.3 the diameter of shaft subject to twisting only.

BOLTS.—(Seaton) d = diameter of bolts; n = number of bolts; K = distance of center of bolt from center of shaft; D = diameter of shaft (subject to twisting moment only).

$$d = \frac{D}{2}\sqrt{\frac{D}{n \times K}}.$$

Take K = .8 D; then $d = \frac{D}{2}\sqrt{\frac{1}{0.8n}}$,
n is usually taken one for every 2 inches diameter of shaft.

Question No. 3.—Design a piston rod and a connecting rod for a given engine.

PISTON ROD.

$$\frac{fa}{1 + \frac{r}{4000}} = W.$$

W = boiler pressure × area H. P. piston.
f = 4500.
a = area of rod.
r = ratio of length to least diameter.

(Rankine) $\frac{fs}{1 + \frac{16a}{9}\left(\frac{l}{h}\right)^2} = P$, total pressure on piston.

a = 1/4000 for wrought iron or mild steel.
f = 4500 for wrought iron or mild steel.
S = area in sq. in. of rod.
$\frac{l}{h}$ = ratio of length to least external diameter.

(Seaton) $D = \frac{\text{diam. of Cyl.} \times \sqrt{P}}{F}$.

P = boiler pressure.
F = 60.

CONNECTING ROD.

$R = \frac{f\,A}{1 + 4\,a\,(r)^2}$, where A = area of cross section of the middle of rod.

a = 1/3000 for wrought iron or mild steel.
r = ratio of length to least diameter. (Estimated.)
f = safe working load for iron or mild steel—3000 about.
R = load on rod.

The diameter of the rod given by above rule is for the crosshead end.

At the crank-pin end increase the diameter of the rod, in the direction of its vibratory motion by continuing its taper, and reduce the thickness at the sides by planing, making the area of cross section = 8 to 10 per cent greater than at the crosshead end.

To determine the load on the connecting rod, R is found from the formula

$$R = \frac{P \times 2L}{\sqrt{4L^2 - S^2}},$$

where P = load on piston.
L = length of rod.
S = stroke of piston.

If D = diameter of middle of rod; L = length of rod; $K = .03$ effective load on piston in lbs., then

$$D = \frac{\sqrt{L \times K}}{4}.$$

In calculating the maximum strength of cap bolts at bottom of thread, use 5000 lbs. for iron, and 6000 for mild steel, per sq. in. of section.

Question No. 4.—Work out the principal dimensions for the cylinders of a given engine, including steam ports.

CYLINDERS.

To find the thickness of a cylinder:

$t = \frac{Pd}{3700} + c$, where t = thickness in inches.

p = maximum steam pressure in cylinder; d = diameter of cylinder in inches; c = allowance for boring on account of variation of thickness of metal, reboring, etc., and varies with diameter.

A safe allowance is, $c = .01\ d$.

The least thickness required to ensure a good casting is given by the formula $t = .18\ d$, and this formula must be used when it gives a higher value than the first formula (for cast iron).

The size of the ports will be based on the velocity of steam into the cylinders, viz.: 125 feet per second for H. P.; 150 for I. P. and 175 for the L. P. (these velocities are high). The exhaust should be, say 100 for H. P., 125 for I. P. and 150 for L. P. Say one piston valve for H. P., 2 piston valves for each L. P. and I. P.

The port opening for H. P. cylinder is given by the formula

$$\frac{\text{Piston speed per second} \times \text{area of H. P. piston}}{125} = \text{area of port}$$

opening.

Assuming a port opening of 2 inches, and remembering that 1/4 of the area of the opening is taken up by ribs, we have:

$$\frac{\text{Area of port opening}}{.75 \times 2} = \text{circumference.}$$

$$\frac{\text{Area of port opening}}{.75 \times 2 \times 3.1416} = \text{diameter of piston valve.}$$

If the I. P. and L. P. have two piston valves, take half the area of the opening and find the corresponding diameter.

For the I. P.,

$$\frac{\text{Piston speed in ft. per sec.} \times \text{area of piston}}{150} = \text{area of port}$$

opening

For 2-inch opening,

$$\frac{\text{Area of port opening}}{.75 \times 2 \times 2 \times 3.1416} = \text{diameter of each piston valve.}$$

In a similar way we establish the L. P. port opening.

The exhaust port for the H. P. will be $\frac{2 \times 125}{100} = 2.5$ inches so the port should be 2.5 inches wide and should be open to steam 2 inches.

In a similar way we establish the I. P. and L. P. port openings.

For thickness of the cylinder flange (see Seaton). T = thickness; f = a constant = thickness of cyl. + .25.

$$T = f \times 1.4 = (t + .25)\ 1.4.$$

$$T \text{ of cylinder head} = f \times 1.3.$$

For thickness of piston and packing, see Seaton.

Question No. 5.—Give a brief outline of the process of making cast iron, explaining how the different qualities are produced.

CAST IRON.

In making cast iron the nature of the ores governs the flux required. The fuel, which is charcoal, coke and anthracite coal, modifies the iron made, as does also the temperature maintained in the furnace. The ore is in some cases roasted to expel the volatile matter and moisture. It is then mixed with a certain quantity of flux, and the fuel is added to make a charge for the cupola blast, either hot or cold. The nature of the cast iron is determined by the charge. Commercially, there are six grades, Nos. 1, 2 and 3 are foundry iron, No. 1 being the softest. Nos. 4, 5 and 6 are for the forge.

Question No. 6.—Give a brief outline of the common method of making wrought iron bars or plates.

WROUGHT IRON.

Pig iron Nos. 4, 5 and 6 is put into the puddling furnace and partially melted or puddled. When in a pasty condition the ball is taken out and sqeezed or rolled into blooms, which are cut up, piled, raised to a welding heat, and hammered into bars, which bars are rolled into bar or sheet iron.

The oldest and most expensive method was to take the charcoal pig and heat it in an open forge filled with charcoal until in a pasty mass. This was then taken to the squeezer, squeezing out the silicates and impurities, and then working into blooms, which were made into bar or plate iron as required.

Question No. 7.—Describe briefly the principal methods of making steel used in machinery and structural work.

There are two processes of making machinery or structural steel, the Bessemer process and the open-hearth process.

(1) The converter or Bessemer process. In this process molten pig is run into the converter, which has a basic lining. The vessel is then inverted and air is blown through until the metal decarbonizes to a little below the desired point. It is then recarbonized by the introduction of ferro-manganese or of spiegeleisen. The time occupied is about 18 minutes for each charge.

(2) There are two methods of producing steel by the open-hearth process, the acid and the basic processes. In both methods the details of construction of the furnace are the same, except as to its lining.

In the former method the lining is high in silicon and has practically no effect on the charge. The charge must be as free as possible from impurities, such as phosphorus, and is made up of scrap, pig, and more or less ore, according to practice. It takes from four to twelve hours to complete the process. In this as in the Bessemer and the basic processes the charge is decarbonized a little below the desired point, the silicon and manganese being meanwhile burned out. The charge is then recarbonized as in the Bessemer process.

In the basic process the furnace is lined with dolomite, and lime is added to the charge as may be found necessary. The object is to keep the slag in a basic state and so to dephosphorize and to some extent desulphurize the charge. The advantage of the basic process is that a cheaper grade of pig can be used to produce the same grade of steel.

Question No. 8.—Explain in a general way the manufacture of various kinds of brasses or bronzes, explaining how the proportions of the ingredients affect the principal qualities, such as strength, hardness, brittleness, etc.

Brass or bronze is made by mixing copper, zinc and tin. The metals of the highest melting points are first melted, and experience alone can give any degree of perfection in making the required bronze or brass.

A mixture of copper and zinc is usually called brass, and is fairly tough but too soft. All others are called bronzes. An important point is to have pure copper and other metals. The various proportions give metals of different qualities. Tin gives toughness to metal. Zinc makes a soft metal. A very tough, strong metal is made of copper 50, zinc 45, iron 5; this mixture is about the same as Tobin bronze. Manganese has tendency to make metal brittle; antimony has a similar effect and also hardens. Naval brass is 62 copper, 1 tin, 37 zinc. Many of these mixtures are benefited by rolling. Hammering adds to the hardness. For bearings use a mixture of copper 6, tin 1, zinc 1/4. Ordinary metal used in the service is 88 copper, tin 10, zinc 2; a very strong spring metal is made by the use of phosphor tin instead of ordinary tin.

It is best to use new material, but good results in large castings have been obtained by the use of old composition of known proportions.

Lead reduces the strength.

Aluminum strengthens.

The greater the percentage of tin, the harder the mixture. Muntz metal is 3 of copper, 2 of zinc.

Question No. 9.—Explain in a general way the manufacture of the so-called "white metals" or "anti-friction" metals, the way in which they are used, and the reasons for their use.

The composition of many of the so-called *white metals* is secret.

A good white metal is made by mixing two mixtures, one of copper 1 and tin 6, and the other of antimony 1 and tin 6.

Babbitt metal is 10 parts tin, 1 copper, 1 antimony.

Fenton's white metal, used for stern bushes, etc., is 79 parts zinc, 16.6 tin, and 4.4 copper, and is fairly tough and hard. It may be used in water, and resist wear very well.

Deoxidized metal is 96 parts tin, copper 4, antimony 8.

The white metals are used in bearing brasses to reduce friction and are put in in several ways, principally in slabs or projecting from round holes. The bearing surfaces should stand about 1/8 beyond brass. They are usually cast in place and peaned, then bored and scraped to a fit.

The advantages of these white metals are that they can be easily renewed, and can be fitted when hot. They do not cut the bearings like hot brass, are not liable to crumble, and the methods of fastening them to brass leave oil ways.

The white or anti-friction metals are melted and poured at temperatures that will char white pine.

Question No. 10.—Explain the methods of framing used in war vessels constructed of steel, particularly in the space to be occupied by machinery.

In large steel vessels of war there is generally no external keel, the flat plate keel being used, consisting of an inner and outer plate to which a vertical keelson plate is secured by double angle irons. The plates of which the vertical keelson plates are made are as long as possible, at least twelve feet, and are joined together by double butt straps extending between the upper and lower keelson angle bars. The keelson angle bars are worked in the longest lengths procurable, and their ends are connected by pieces of angle bar long enough to take three rivets in each flange on each side of the joint. Throughout the inner bottom, the butt straps and angle irons are caulked, thereby forming longitudinal water-tight divisions in the double bottom space. On each side of the vertical keelson there are two or more other longitudinal frames or "longitudinals," which stand at right angles to the bottom plating and frames. These are designated as the 1st, 2nd, etc., longitudinals from the keelson respectively, and, in a ship built on the longitudinal system, are continuous throughout the length of the ship as far as they can be carried.

The transverse frames throughout the double bottoms in such a ship are worked in short lengths or intercostally between the longitudinals. Beyond the limits of the double bottoms the frames are continuous from the outboard longitudinal to the protective deck, and from thence to the upper deck. Above the turn of the bilge intercostal longitudinal stringers are worked between the frames.

The 2nd or 3rd longitudinal on each side of the keelson in the double bottom is made water-tight, so as to form water-tight spaces between themselves and the vertical keelson. The intermediate longitudinals have holes cut through them sufficiently large to allow easy access for cleaning and painting the compartment and for drainage. The transverse frames throughout the double bottom spaces are placed from 3 to 4 feet apart and consist principally of angles, reverse angles and bracket frames, worked intercostally between the longitudinals. When more rigidity is required, as under the engines, solid plates are put in, lightened by holes.

Under the engines and boilers, longitudinal girders are built to stiffen the ship and to sustain the weights.

Another system of framing is called the transverse system. In this the frames are continuous from the keelson up to the rail or to the armored deck (if such a deck be fitted), and the longitudinals are built intercostally between the frames.

The frames are connected together athwartships and the decks are formed by the beams, which are also again braced by steel longitudinal deck stringers, secured to the beams, in case of a ship not having a complete steel deck.

Question No. 11.—Explain method of water-tight subdivision used on board war vessels.

The water-tight subdivision of ships is accomplished by fitting horizontal water-tight decks or shelves, vertical transverse and longitudinal bulkheads, and in many ships by having an inner bottom, the double bottom being divided up into a number of water-tight compartments.

In ships built on the bracket system, solid plates are substituted for the brackets every 16 or 20 feet. The spaces included between the inner and outer skins, the vertical keelson, the water-tight frames and the water-tight longitudinals form water-tight compartments. The double bottom in some of the largest war ships is divided in this way into more than a hundred water-tight compartments.

The forward transverse water-tight bulkhead is called the "collision" bulkhead and there is sometimes a similar one fitted aft, which is made tight where the shaft passes through by a stuffing box. Other transverse water-tight bulkheads are worked into the ship at specified distances, dividing the machinery and boiler spaces into a number of compartments.

These, at each end of the double bottom, extend to the outer bottom, and all extend up at least to the armored deck, and often to the next deck above.

The main longitudinal bulkheads are the middle line bulkhead and those forming the wing passages and coal bunkers. The middle fore and aft bulkhead, in twin-screw ships with vertical engines, separates the two engine rooms, but this cannot be used in twin-screw ships with horizontal engines.

In the latter case the engines are placed in compartments one ahead of the other. The water-tight bulkheads are stiffened by angle or tee irons running vertically on one side and horizontally on the other.

The subdivision of the ship into water-tight compartments should be at least such that, if any two compartments should become filled with water, the ship will still have an excess of buoyancy and remain in stable equilibrium.

Question No. 12.—Explain the framing and working of plates at the stern post and where the shaft tubes are attached.

[NOTE BY REVISER.—The answer to this question is missing from the original notes, and as a subject belonging almost entirely to the subject of shipbuilding, it has been deemed wise not to take it up here.]

Question No. 13.—Explain the drainage system and its connection to the engine-room pumps.

The drainage system of a ship is for collecting the water to be pumped out so as to make it accessible to the ship's pumps.

For clearing water from the main compartments above the inner bottom, main and secondary drain pipes 12 to 14 inches in diameter are worked through the double bottom, one on each side of the vertical keel plate and extending throughout the limits of the double bottom, two cisterns for each drain pipe being fitted to receive the drainage. A large pipe is fitted to each drain pipe in each compartment and provided with non-return valves at the inner skin, which valves can be conveniently operated by means of rods from above the water line of the ship. Water collected above the water-tight longitudinals, drains through small branch pipes to the main and secondary drains, and the compartments near the ends of the ship outside the double bottom space are drained in the same manner. The water collected on the inner skin in the engine and fire rooms is usually conveyed to the main and secondary drains through short drain pipes provided with strainers flush with the skin and with non-return valves at the junction with the large drain pipes. Sometimes a separate system is provided for freeing the crank pits from water, though they usually drain direct into the main cisterns.

To free the double bottom compartments a suction pipe provided with a strainer is fitted in each compartment and passes through the inner skin with a water-tight joint.

These pipes are connected to manifolds provided with valves for each pipe and also with a valve connecting with the suction pipes of the various pumps, both steam and hand. This admits of pumping from any one of the compartments independently of the others.

The main bilge pumps (if provided) will pump all ordinary amounts of water collected, and they are connected with the main cisterns of the main drains. The main circulating pumps can be utilized for freeing the bilges of large amounts of water, discharging either through the condensers or directly overboard.

Question No. 14.—Explain the precautions to be taken in attaching valves to the hull to maintain the strength and prevent corrosion.

Each valve is attached to the hull by means of a suitable ring riveted to the hull and caulked. Holes are drilled (not through the rings) and tapped. Manganese or Tobin bronze bolts are used to secure the valves to the strengthening rings.

A zinc ring is bolted to the shell, forming a lining for the hole to prevent corrosion. When strainers are used they should be attached to the valve chamber and not to hull.

The hull must be kept well painted.

Where the valve is to be on the inner skin the same precautions should be taken, and a wrought steel or cast pipe must be riveted to both inner and outer skins.

Stuffing boxes are fitted at the inner skin around pipes which are not riveted to that skin.

Question No. 15.—Explain the fitting of decks and framing of hatches near the machinery compartments.

Where hatches are fitted for engines and boilers, the deck beams are cut, and a fore and aft frame fitted and secured by angle plates riveted to the fore and aft pieces and to each of the cut beams. These are supported either by fore and aft bulkheads or by stanchions.

Along the deck on each side of the hatches is a fore and aft plate riveted to the beams and frames, thus forming a stringer. Angle irons are riveted around openings for the hatches and a composition casting (rabbitt) is riveted at each corner, to which the plates are secured, thus forming the combings. At the upper sides of these plates half round beading is riveted.

Question No. 16.—Explain briefly, center of gravity, center of buoyancy and metacenter. Discuss briefly the considerations that effect stability and stiffness.

The center of gravity of a vessel is the point through which the resultant of the forces of gravity acting on each particle of the mass of the vessel, acts in a vertical direction. It is a fixed point in the vessel, and remains unchanged as long as the disposition of her weights remains unchanged.

By the buoyancy of a ship is meant the upward pressure beneath or the support given her by the water.

The *weight of displacement* of a ship acts vertically downward through its center of gravity. Hence also, the upward fluid pressure (or buoyancy), must be equal to the weight of water displaced, and must act through the center of gravity of the displacement. This point is called the "center of buoyancy."

In case of a vessel floating at rest in still water, the only forces acting vertically are the weight of the ship downward through the center of gravity, and the buoyancy upward, through the center of buoyancy, and since these balance, the center of gravity of the ship, and the center of buoyancy, must be in the same fore and aft vertical plane. If the ship be heeled by some force, the center of gravity of the ship is in the same position as before, but since the shape of the volume of displacement is changed the center of buoyancy will also be changed, and a vertical line through this point will cut the original vertical plane passing through the center of gravity at some point. This last point is called the "metacenter." The vertical distance between the metacenter and the center of gravity is called the "metacentric height."

A ship is said to be in stable equilibrium when the metacenter, under the conditions given above, is in the vertical plane above the center of gravity. On the other hand if the metacenter is in the vertical plane below the center of gravity the ship is in unstable equilibrium.

The vertical distribution of the weights in a ship determines the height of the center of gravity and consequently the metacentric height.

By altering the shape of the ship and varying the under water form, the metacentric height, and consequently the stability and stiffness of the ship, may be altered, still retaining the same displacement.

Subject No. 6.—Economics of Machinery.

Question No. 1.—Explain briefly the advantages and disadvantages of high steam pressures and multiple expansion engines both for marine machinery in general and for war vessels.

Where high pressure and multiple expansion engines are used, less space is occupied for a given I. H. P., and the loss due to great differences of temperature is reduced by the use of a number of cylinders.

The greatest gain is in the uniform crank effort, obtained thereby, which gives a great saving in wear and tear of machinery. The machinery can be made much lighter as a result. Where high pressures are used, the disadvantage is in the high temperature and consequent difficulty in making joints and in the use of lubricants, and also in packings burning out. Also there is more expense in building, and greater care must be taken in the selection of material.

It is not thought that there is any gain except from a mechanical point of view. The wear and tear is of course less, and the machinery is more accessible and more easily handled, as the parts are smaller.

Question No. 2.—Discuss briefly the advantages and disadvantages of the various styles of valve gear and valves in general use, and of those which are used in special cases where saving of weight and space is important.

The valves in general use are slide valves, either flat or cylindrical, but usually piston valves for marine use. The flat slide valve is in various forms, usually the single or multiple ported kind.

The advantages of the common slide valve are its cheapness of construction and maintenance and its reduced clearance for ports. The disadvantages are its size and great friction for high pressure, causing much work to be lost in moving the valves; also its great weight. The piston valve's only advantages are its lightness, and the fact that it is balanced. It is more difficult to manufacture and to keep in repair, and it has excessive clearance.

The gears usually used to control valves in marine use are the link, single eccentric Marshall and modification, and the Joy or radial gear with modifications.

The advantages of the link are simplicity, and ease of keeping in repair. Its disadvantages are inequality of motion due to angularity, and the great space occupied. With the other gear we can have the motion required for the valves, but have the disadvantage of too many connections, the excessive wear due to that cause deranging the movement, unless the rods are constantly watched and the pins frequently renewed. It takes less space than the link and is lighter and more easily operated.

Question No. 3.—Discuss briefly the considerations that govern the choice of a particular style of boiler, noting the relative merits of shell and coil boilers.

In selecting a style of boiler, the choice is governed by the pressure to be carried and the space to be occupied by, whether rapid or slow combustion is desired, and by the rate of movement of the gases.

The relative heating and grate surfaces, and the speed of the engine must also be considered.

Water tube boilers are, for small high-speed craft where weights are to be carefully considered, better than shell boilers, and from recent developments, for men-of-war, the water tube boiler, in connection with the ordinary shell boiler, has succeeded very well. There is a likelihood in the future of a more extended use of water tube boilers, which for the same power, cost less than the shell. They are more easily kept tight and are just as easily repaired. They require clean, fresh water, whereas the shell boiler can more readily use salt or muddy water, as it is easily accessible for cleaning. The coil type of boiler cannot be cleaned internally with any degree of certainty.

Question No. 4.—Discuss the methods of propulsion in common use, giving important features to be secured in an efficient propeller, and explaining why the form of propeller now in use is most desirable; or what other form, if any, you think would be preferable.

All vessels are propelled by a stream projected in the opposite direction to the motion of the vessel. This stream may be projected by a jet from a pump, turbine or other means, by paddle wheels, or by a screw.

The principal methods now used, are paddles for river service, where light draft is required, and the screw for sea.

The great weight of machinery required and space occupied precludes the use of paddles, except for special service.

The screw should be designed to get maximum depth of blade below the surface, and the diameter is limited by excessive speed. The pitch should be suited to the speed of engine required. The area should be a fraction of the section immersed, modified by the lines of the ship. The screw's surface should be finished and polished to reduce friction to a minimum. The speed of screw should be such that the work of friction of the blades is a minimum. The true screw is the best form of blade, from results of actual practice, and great care should be taken that the pitch of each blade is accurate and equal to that of each of the others.

The screw should be accurately balanced.

Question No. 5.—Discuss the question of the methods ordinarily employed in securing great power in marine machinery on light weight; showing what is necessary, how far it is safe to go, and what precautions in inspection must be observed in order to secure perfection in material and workmanship.

$$\text{I. H. P.} = \frac{\text{Area of cyl.} \times \text{speed of piston per min.} \times \text{mean effective pressure.}}{33{,}000.}$$

From the above equation, we can readily see that the power in I. H. P. varies directly as the area, speed of piston and pressure represented by A, S and P, respectively.

The area varies as the square of diameter, so we use the diameter itself.

$$\text{I. H. P.} \backsim D^2 \times S \times P.$$

In order to increase the power, it will be necessary to increase D, S or P. D is limited by the space occupied, so we make S and P as great as possible. P is limited by the strength of the boilers and by the temperature due to P, on account of the destruction of packing, etc. S is limited by its action of the screw in the water. By using the highest possible speed and highest pressure we get increased horse-power on less weight of machinery.

This power of machinery is not to be increased to the danger limit of the material used in construction, great care being exercised in considering the flexibility of the material used.

The following precautions in inspection of material and perfection of workmanship must be observed:

The greatest care must be observed in inspection of material to see that it is of the required standard and free from flaws or imperfections, and in no case should material be passed of which there is the slightest doubt.

The workmanship must be of the best, great care being taken in fitting and lining up. Where high pressures are used the piping must be specially worked out to see that there are ample drains and no pockets.

The working parts must be carefully adjusted, all journals, piston and valve rods and crank pins being carefully ground true. Metallic packing should be used where possible.

All cylinders and valve chests and connecting pipes should be tested by pressure. Clearances should be measured accurately by oil or water (oil preferred) and the clearance of cylinders should be accurately adjusted. The valve movement should be tried by jacking the engines. Stop valves should be easily accessible. When possible, connections should be made to open and close the stop valves from deck outside of the boiler compartments. The piping should be so arranged that it is readily accessible and so that it can be easily removed for repairs. Steam joints should be made of metal flanges, and should be brazed for steam pipe. Safety valves on boilers, receivers and cylinders should be set to required pressure. A separator should be placed in steam pipe between boilers and engine, as near as possible to engines, and should be properly trapped.

APPENDIX A.

THE LOGICAL ARRANGEMENT OF THE MOTIVE POWER OF WARSHIPS.

BY REAR-ADMIRAL GEORGE W. MELVILLE,
Engineer-in-Chief, U. S. Navy; Honorary Member.

[Read at the Fortieth Session of the Institution of Naval Architects, March 23, 1899; the Right Hon. the Earl of Hopetoun, G. C. M. G., President, in the Chair.]

[NOTE.—This paper is so complete and, in view of the increase in the use of triple screws abroad, so full of interest, that it is here reproduced as a whole. Thanks are due to the author for permission to republish.—ED.]

In the preparation of a set of tables showing the power required to drive a vessel of a given displacement at a given speed, data have been used which were gathered from the results of about two hundred trials of nearly as many ships. From this set of tables, there was developed the remarkable fact that the propulsive efficiency of vessels with three screws is, in almost every case, above that of ships of approximately the same size, speed and general lines, but fitted with only two sets of engines. Attention has heretofore been drawn to the remarkable performance of the U. S. cruisers Columbia and Minneapolis on their trials. Recently, as the number of high-speed ships has increased so greatly, it has been very interesting to those who were responsible for the plans of the machinery of these cruisers, to note how well they have maintained their position in the front rank of all naval vessels. These five-year-old ships, ten years old in design, are still among the most economical vessels in the world's navies as far as propulsive efficiency goes.

There are many reasons for the superiority of the Columbia and Minneapolis over other vessels of the U. S. Navy, built at about the same time. The stream lines of these ships are remarkably easy, and the resistance is low, these factors giving—it is claimed by many—a total resistance below that calculated from results of trials of less carefully designed vessels. This is no doubt true to a certain extent, but comparison between these

American ships and those of other nationality, but of approximately the same lines and speed, shows still the superior efficiency of these vessels. The main cause of this increased efficiency lies in the use of three engines and propellers for the motive power. Not only has the propulsive efficiency been benefited, but there are so many engineering and tactical advantages arising from the use of triple screws, that it may be readily seen why so many ships are now designed for this system of propulsion.

The advantages due to the use of three propelling engines, instead of two, have been pointed out before, but it may be of interest to recall some of the reasons leading to the adoption of this system for the Columbia and Minneapolis. It was not possible, at the time of the design of these vessels, to obtain, in the United States, sufficiently large forgings for such great power as it was desired to install, if the twin-screw system were adhered to. Other chief factors were the greater safety of the machinery and of the ship due to the use of three screws, as well as the then conjectured, but now proven, increased economy due to the use of triple screws.

To-day we have a somewhat different case presented in the design of high-powered cruisers or battleships. The conditions have changed. We are confronted no longer by the probable inability of the steel manufacturers to furnish forgings and castings of any size we may desire, for any power yet designed to be installed in a man-of-war. On the contrary, we have examples of engines of about the power we desire to use for our fastest vessels already constructed in the United States, and giving complete satisfaction, not only to the designers, but also to the builders and to the owners. The science of metallurgy has made such progress in the last decade that we are now able to specify, regularly, steel of 95,000 pounds tensile strength, 21 per cent elongation in 2 inches, and to stand cold bending to an inner diameter of 1 inch without showing cracks or flaws. Improved methods of forging, our more thorough knowledge of fluxes, the exclusive use of nickel steel for high-grade engine construction, the judicious employment of annealing and tempering—all these, combined, enable us to secure stronger materials, and now we obtain a vast increase of power without a much greater weight than that required ten years ago for the lower powers then prevailing. The reduction in weights is most apparent in the moving parts. This is an important point, as it has meant that the growth in power has not been accompanied by an increase in vibration, a matter that is likely to limit speeds of rotation in the future. We are no longer forced to divide the power among three shafts because of the impossibility of obtaining one sufficiently large to transmit half the power. We can now secure in the home market all of the materials needed for the machinery of the highest power yet planned.

There are many other considerations, however, both tactical and engineering, which make it still advisable, at least for the highest powers, to use the triple-screw method of propulsion for our men-of-war.

The most evident advantage from the use of three screws is the consequent subdivision of the power. This is of particular moment on war vessels, where the possibility of disaster in battle is to be considered, as well as that of accident in time of peace. Not only does the increased number of engines decrease the probable amount of power that may be disabled at any time, but also the chance of fatal injury to the ship, through its motive machinery, is lessened greatly. The danger from a shell is decreased. It would require three shots penetrating the steel deck to completely disable a triple-screw ship, as against but two in the case of a vessel fitted with twin engines. This, however, is assuming a possibility which may not be a fact, that a shell will not have any disastrous effect outside of the compartment in which it explodes. It is probable that the vertical bulkhead between the engine rooms cannot be so entirely depended upon as to restrict the effects of an explosion. It is quite possible that a single very lucky shot might disable completely a twin-screw war vessel. If so, then it would surely take at least two such shots to inflict corresponding injury on any ship with triple screws. In case of the wrecking of any single engine the amount of power lost with twin screws would be one-half, as against the much less reduction of one-third in triple-screw ships.

It may be urged—and with justice—that the engines of our men-of-war are already well guarded from shell fire. If it can be shown, however, that the protection can be increased without consequent loss in other directions, it will surely be well worth while to adopt the system affording greater security. In the old days of sailing ships many a battle was won, sometimes against superior force, by the disablement of the sail power of one of the combatants. After the motive force of any fighting ship was gone, she was at the mercy of her foe. In our time, when battleships have a fair all-round fire, the likelihood of this is somewhat reduced; but it is still apparent that any ship which is inert on the sea is far the inferior of her dirigable enemy. Any system which increases the chance of securing and keeping the "weather-gauge" in battle, must be good.

Should one of the propelling engines be disabled, there is not nearly as much interference with what is called the handiness, the steering qualities, of the ship, if there are three screws, as if there be but two. With twin screws, and one only in use, it is necessary, in order to keep the vessel on her course, to use a helm angle of from 6-1/2 to 10 degrees. This is the amount when the screw of the idle engine is left to revolve freely. We have attempted to get over this difficulty by using diverging shafts, and thus reducing the turning effect of the engines; but this is objected to by the deck officers, who wish for vessels which can readily "turn on their heels." Of course, the less the fraction of the power that is disabled, the less the ill effect on handiness.

For war vessels it is desirable to make the water-tight compartments as small as possible. The reduction in the smaller sizes of engines in three-screwed ships leads to this end; and, as will be pointed out later, this is effected with no increase in the total engine room space.

One of the greatest advantages from the use of triple screws is that smaller propellers are required for the same total power. This particular in itself presents sufficient advantages to justify the use of three engines on warships—advantages which are so practical, engineering and tactical, that it is surprising that this point has not been more thoroughly developed.

A very large part of the loss of power at the propeller is due to the frictional resistance of the water to the passage of the propeller blade. This resistance increases with any increase of the peripheral speed of the blades, and low speed will be advantageous in this regard. It is assumed, of course, that due account is taken of the ratio between the pitch and diameter of the screw. If this ratio be not unreasonably increased, however—and with the large hubs used in current designs, this ratio may be profitably rather high—it will be a great gain from an economical standpoint to reduce the peripheral speed. With very high speeds and powers this speed is now very near the critical point beyond which the friction is excessive, and the effects of cavitation begin to be felt.

The decrease of pressure upon the forward sides of the screw blades, at high velocity, is not a negligible quantity. The matter of proper propeller design is too complicated to be more than glanced at here, but it must be evident that to reduce the peripheral speed would be advantageous in the cases of the screws of large diameter necessary in the application of very high powers.

Now, the use of three screws allows a reduction in diameter of screw of over 20 per cent, and while, as will be pointed out, this is accompanied by an increase in the number of revolutions, the speed of periphery may readily be reduced below what is required in twin-screw practice.

At the stern of the ship, amidships, in the following wake always present to some extent with the most carefully designed hulls, the effects of a large screw are not so signally bad. I think that "cavitation," or the tendency thereto, is reduced greatly in this following wake, and, on that account, I believe that a considerably greater efficiency is obtained from the screw at the stern post than from those on the quarters. Whatever the cause, this increase in efficiency is so well shown by the results of trials that it can no longer be questioned.

I mean, of course, the trials of large ships, not tank experiments. The latter serve very well for determining the actual resistance of a hull; but not for fixing the economy of propulsion, or the ratio between the towing and indicated powers. It is in the increase of efficiency, and not in any decrease in resistance, that the economical advantage of triple screws must be found.

No test of a propeller can be held to have so much value as a test upon ships. Model experiments of propellers are not satisfactory. It requires experiments with the full-sized screw, working at the designed pitch and at its designed speed, under its full load of work, to give us conclusive results. Trials under these conditions show, as I have said at first, a considerable advantage due to the use of triple screws.

Investigation along this line has not yet proceeded far enough to enable me to give more than tentative figures as to the propulsive efficiency due to the different methods of arranging the screws. It is, however, certain that there are gains from both the use of small screws, and of a screw working in the following wake, and that these gains would naturally grow with an increase in speed. Speaking only of full power trials, it will probably be found that, up to some low speed not yet determined, it will be best, from the economical standpoint only, to use a single screw; beyond this point it will be found that the use of twin screws would tend to a reduction in the power required for a given hull and maximum speed, and that, at any time where twin screws are good triple screws are better. I estimate the average economy over single-screw ships from the use of twin screws, as about 8 per cent for vessels of maximum speeds from 12 to 20 knots, and I consider that triple screws are more economical than twin screws by from 5 per cent for 15-knot ships to 12 per cent for those of 24 knots speed. These figures are approximate; but they are from trial data of many ships fitted with the different methods of screw propulsion.

I have discussed this point at considerable length, principally to develop the following conclusions:

(1) The use of triple screws leads to a considerable economy at the highest speeds.

(2) Decrease in size of screws is peculiarly economical as regards the wing screws, and

(3) To evenly distribute the ill effects of high peripheral speed, and to take advantage of the following wake, the center screw should be made larger than the wing or side screws. (See Figs. 1 and 2, Plate V. A.)

But there are many other advantages due to the smaller screws, particularly the smaller wing screws, and especially for men-of-war.

In ramming an enemy, if all goes well, there would be little difference between the twin and triple systems, but a glancing blow from either forward or aft would certainly take off the enemy's side screw if, as in twin practice, it projected beyond the counter; and, later on, as the ships rubbed past each other, one's own side screw would be broken, under the same condition of projection. But, with a small screw, such as can be had in the triple system, neither propeller would be damaged, and the stern screw would be safe in any event. This point is of value, too, in ordinary cruising, where a floating log or a pile in a river would disable a propeller of a twin-screw ship, while the obstruction would have been pushed clear of the smaller propeller of a triple screw by the ship's hull. Going alongside dock also—that bugaboo to commanders of high-powered, fine-lined, speedy, twin-screw vessels—would be made much easier.

The shorter shafting required for getting the smaller propellers clear of the ship would allow these screws to be placed further forward, where they would be better protected by the hull. This shorter shafting would also decrease the strains on the propeller shafting in bad weather, and would often obviate the necessity of an extra supporting strut, giving, as well, a decreased danger of fracture, and the possibility of decreasing the weight.

The fact that, with smaller screws the tips of blades are lower in the water than with the twin-screw system, gives advantages. The design of the upper and fuller stream-lines could be considerably freer. If it is considered advisable (and I have no doubt the hull designers will show that this gain is not of great moment where a central screw is fitted) this advantage could be passed over in favor of giving the wing shafting a slight inclination upward, so as to obtain a horizontal thrust when the stern of the vessel settles in the water at full speed. Ordinarily, however, the squatting of the ship would be insignificant. The fact must not be overlooked that, the lower propellers are placed, the freer the access of water, and the more perfect the action of the screw.

With tips of blades well buried, the danger of racing is decreased, each extra foot of immersion reducing it. Any one who has stood by the throttle, checking the engine with the heave of the ship, appreciates fully this advantage. The central screw, of course, would never race except in a sea where the ship was pitching heavily; while the side screws, being well forward and deep in the water, would probably never give trouble in the worst of seas.

When the use of three screws was first proposed, the idea prevailed in the minds of most engineers that the "race" of the water from the side screws would materially affect the action of the central screw. The error of this supposition was fully shown by the trials of the Columbia and Minneapolis. In the Columbia the pitch of all screws was made the same. The trials of this ship having shown the revolutions of the central screw to be less than those of the wing screws, the pitch of the central screw on the Minneapolis was made 6 inches less than that of the side screws. On the trials of the latter vessel the speed of rotation of the central screw was almost precisely a mean between the speeds of the two side screws, which differed slightly in pitch. This result was obtained without any "jockeying" of the throttle or change in the cut off.

Attention has been called to the feasibility in the triple system of securing a greater number of revolutions owing to the reduction in diameter of the propeller giving decreased friction of the blades. This matter of increased speed of rotation affects directly the efficiency of the machinery, especially in warships, where the stroke of the engine is limited by the height below the protective deck. The piston speed must be high to get the required power from modern machinery without too cumbrous low-pressure cylinders. Any increase in piston speed, or in the number of revolutions, decreases the condensation in the cylinders, as the item of time is one of considerable importance as far as this condensation is concerned. And, further, as a consequence of greater piston speed, we obtain lighter engines and shafting. For small powers, it is generally possible to obtain great piston speed in our low naval engines, by a great number of revolutions; but there has been pointed out the difficulty of obtaining efficient propellers at high rotative speeds, for transmitting great powers. We know, of course, that it is possible to get an efficient propeller for the very highest powers yet used; but these propellers must be of great diameter in large ships, and in the United States we look into the matter of draft very closely. Our vessels are built for entering comparatively shallow harbors, and it is not easy to secure a screw that will be efficient, and that will fit on a 22-knot, 12,000-ton ship of no more than 24 feet draft. There must be a certain minimum immersion of the screw blades, and this must be greater for twin-screw than for single-screw vessels, because of the rolling of the ship. It is necessary also to have a considerable difference in level between the keel and the lowest part of the screws in a twin-screw vessel. It will surely be difficult, and, I believe, impossible, without the use of high glacis plates, to obtain satisfactory machinery for twin-screw ships under the conditions named, 22 knots, 12,000 tons, and 24 feet draft.

In the design of marine machinery, it is important that the ratio between the stroke and the diameter of cylinders be kept sufficiently high. This ratio is necessarily low in all naval vessels, as compared with the merchant service, on account of the necessity of keeping the machinery below the protective deck. Of course, the larger the power and size of the low-pressure cylinder, the longer the stroke should be, and therefore the greater the height of engine room required for a properly designed engine. The greater the draft, the greater the possible height of engine room, and, for the same number of revolutions, the greater the piston speed. It is unquestionable that, where more than, say, 10,000 horse-power is to be transmitted through a single shaft, under present conditions of speed and displacement, the number of revolutions will be limited by the propeller. We in the United States Navy, having ships of very light draft, as compared with other fleets, are most hampered in this regard.

It has been shown that the use of triple screws would tend to a decrease in the volume of the cylinders required for giving the powers. This is quite apart from the fact that the power is divided into three parts instead of two, and is due to the greater piston speed possible with the smaller screws. It will be seen, then, that considerably more latitude is allowable in the design of machinery for ships with triple screws than would be possible if twin screws were used. If three engines are installed, it is certain that a less height is required under the protective deck than would be necessary for a twin-screw ship.

It is to be noted, then, that the economy of a triple-screw ship is developed not only in more efficient propulsion, but also in the more efficient use of the steam in the engines due to the decreased condensation following the increased number of revolutions and the greater piston speed. The economy of propulsion is thus increased as a result of both increased propulsion efficiency, and of increased efficiency of the engines. A decreased total weight of the machinery is also a natural result of the use of triple screws.

It is, of course, a fact that the use of three engines multiplies the number of engine parts. The resulting disadvantage is, however, much more apparent than real. The Columbia and Minneapolis are examples of the practicability of installing large power in three three-cylinder engines, and this was accomplished with a stroke of but 42 inches. There is no doubt that it would have been necessary to use four-cylinder engines, at least, if twin screws had been used. The absolutely necessary increase in the number of cylinders is thus shown to be but one-eighth. Of course, it is understood that the use of three-cylinder engines is now generally approved. It is merely pointed out as feasible, and as intended to show that the arguments against triple screws, based on the multiplicity of engine parts, could readily be made of practically no weight, if other conditions did not render advisable an increase in the number of cylinders.

Water-tube boilers have now come to stay, at least as far as the United States Navy is concerned. These bring with them steam of high pressure, and cause the use of quadruple-expansion engines for economy's sake. At 200 pounds pressure the quadruple-expansion engine gives sufficient gain to justify its employment. Owing to the low powers of peace-cruising with men-of-war, it is questionable whether it is desirable, with these ships, to design engines for the greatest economy at the highest powers. Unquestionably an arrangement of cylinders which gives the greatest economy at the highest powers produce a markedly uneconomical engine for the lower powers ordinarily used in peace.

The wide variations in present designs show how different designers view this problem. It is extremely complicated, and I am free to confess that much more data than are now available are needed for a full solution. We must know the cost of running the auxiliary machinery, and not only the average power of the main engines, but their range of power must also be carefully considered. It has been thought advisable, however, in the design we are proposing for our latest fast ships, to use quadruple-expansion engines throughout, using thirteen cylinders, in all, in the three main engines. This is a considerable change from the practice of twenty-five years ago, when two cylinders were most frequent. But the fact that this large number of cylinders has been adopted shows that our experience, at least, is that the argument of the multiplicity of parts of the engines has comparatively little weight. The decrease in the size of parts, with the consequent increase in accessibility, in accuracy of adjustment, and in case of repairs, is a natural sequence of the growth in the number of parts, and seems sufficient to overcome the disadvantages. It will be pointed out, further, that the increase in the number of working parts due to the use of triple screws is only apparent, as, ordinarily, there would be not more than eight cylinders employed on our triple-screw ships against ten cylinders that would necessarily be used in the proposed five-cylinder quadruple-expansion engines for our twin-screw ships.

A much more serious objection to the use of triple screws than the multiplicity of engine parts is found in the greater intricacy of the piping plans, and in the increased number of valves required. This objection is serious. Our twin-screw warships are complicated enough at best. This disadvantage has been reduced somewhat, however, by several simple methods. The use of electrically operated auxiliaries has done much in this respect, especially as regards piping outside of the machinery space. Our piping plans are very carefully studied, and are so designed and arranged as to reduce the number of valves to a minimum, and to render plain to the engineer the leads of all pipes. All valves are marked mainly to show the connections. Many of them indicate, as well, the amount of opening of the valve. As a result of this care in the laying out and installation of piping and valves, mistakes in the operation of the valves are made almost impossible, and undue intricacy of the piping plans is avoided. This absence of complexity is especially marked when comparison is made with some of our earlier twin-screw ships.

The growth in number of auxiliary engines, owing to the employment of three main engines, is another disadvantage of the triple-screw system that is much more apparent than real. Ordinarily there is no increase in the number of auxiliaries in use, only an increase in the number available for use; and, as a rule, these uneconomical auxiliaries are worked much more nearly at their rated capacity, and are thus considerably less wasteful of steam. Our experience has been that the auxiliary machinery gives most of the trouble on board ship, and our vessels have been more frequently disabled on account of the failure of these small engines than from any other cause due to the machinery. A larger reserve power in this, the weak part of the machinery, is too great an advantage not to be well worth its cost.

The increase in engine-room force required with the three engines is not excessive, being twelve men at the most. This cannot be considered a disadvantage for warships. The added staff consists entirely of skilled mechanics, and these men are especially useful in making repairs while under weigh. Our recent war experience tends to show the imperative necessity of some such mobile reserve for the maintenance of a vessel, constantly under weigh, in a condition, at all times, of thorough efficiency. With this increase, there is always some one at hand to take the place of any man overcome by heat or sickness, and crippling of the crew, as well as of the machinery, is guarded against. I repeat that the increase in the engine-room force necessitated by the adoption of three propelling engines cannot be counted a disadvantage in men-of-war, under war conditions.

The formation of the stern post and rudder is made somewhat complicated by the use of the central propeller, but not more so than in any single-screw merchantmen, and I apprehend that this disadvantage will not be given great weight to by any designer.

To obtain a proper conception of the advantages of triple-screw propulsion, it is necessary to consider also the latitude afforded by this system in the methods of running the ship under cruising conditions, since either one, two, or three screws may be used. There have been many trials of triple-screw ships under each of these methods of propulsion, and it may be interesting to give a few of the results, which have not hitherto been published, so far as I am aware. Taking a vessel of, say, 12,000 tons, 23,000 H. P., and 22 knots speed, when all engines are used at full power, it is found that:

(1) The power required to drag one screw, uncoupled from the engine and left to revolve freely, is 150 H. P. at 10 knots; 600 H. P. at 15 knots.

(2) If coupled to the engine, at 10 knots speed the power absorbed in dragging is slightly in excess of 300 H. P.

(3) If two screws are dragged, the loss from drag is practically double what it would be with one idle screw for the same speed of the ship.

(4) The loss in power due to condensation in an engine (not the result of expansion of steam in the cylinders, but attributable directly to the heating of the cylinder walls) is almost exactly one pound of steam for each horse-power of the maximum power for each engine. This figure is approximately correct for all speeds, increasing slightly for the lowest speeds. It applies to jacketed engines.

(5) With three equal screws, the center propeller has not sufficient area to give economical results when used alone at speeds above eight knots. With three equal screws, the use of the two wing propellers alone can be depended upon to give a considerable gain in economy for all speeds from 8 to 17 knots inclusive. These results have been gathered from fully authenticated trials, not only of our own ships, but also of triple-screw ships in other navies.

All screws were practically equal in disc area in the trials from which these results are obtained.

With these points known, the problem of the design of triple-screw ships is greatly simplified. The disadvantage of the drag of a screw is measured, and the advantage of the fitting hitherto adopted, which provided for the disconnecting of any idle screw from its engine, is clearly developed. The necessity of giving sufficient disc area of propeller is, as was to be expected, prominently shown by the failure to secure economy with one engine in use, except at the very lowest speeds.

The value of economical engines is so universally recognized to-day that it seems almost unnecessary to mention it; but this value is, in a warship, far greater than the mere saving in the coal bill, though that is an important item. The matter of economy in the use of coal may make all the difference between victory and defeat. Coal endurance limits the radius of action of the ship, and determines definitely the scope of her operations. Of course, we can—as we did recently, in two cases—assist a monitor across the Pacific Ocean in case of need, but that tardy reinforcement might have been too late. Economy at the engines increases the speed of these reinforcing ships where that economy can be gained without a reduction of bunker space; it increases the potential value of each pound of coal, and 10 per cent may often make the difference between success and failure. If this economy were measured alone, and not from the military point of view, it might be proper to consider the question whether three engines have a greater first cost than two of the same total power, but economy means more than that. It means victory, and it is for this that men-of-war are built.

If three screws are to be fitted to a warship, and the design is to conform to the conditions of economical propulsion obtaining on these vessels, as shown by our present knowledge of the effects of three screws upon propulsive and engine efficiency, there appear to be but two practical arrangements. The central engine should be considerably more powerful than either of the wing engines, or it should be considerably less powerful. This follows from the fact that a propeller design which will give in one screw sufficient area for the ordinary cruising speeds up to 12 knots, is nearly impossible if the same screw is designed to be worked as one-third of the propelling system for the highest speed of the ship. The proportions of the screw must be changed to suit the latter conditions. It is evidently not wise, also, to use as much as two-thirds of the full engine power for cruising at one-tenth power. The use of three equal engines is, therefore, out of the question, as far as comparative economy goes. If a small center engine be used, it would be practically an auxiliary. A very large screw necessarily being fitted to secure a fair propeller efficiency at low speeds, when the small engine alone would be used, it would be of practically no value at the highest speeds. I consider, therefore, that it would be far better practice to use a large center and two small wing engines, in which design, under no conditions would there be a useless engine. Of course, either of these plans, involving the use of two different sizes of engines on the same ship, is disadvantageous; but this disadvantage is not so great as a casual view of the conditions would seem to indicate. Engines do not break down in service. Careful designs for the maximum power ensure good working of the machinery. Accidents to the engines are extremely rare, and are due, almost invariably, to some defect in a seemingly unimportant detail. The engine itself, so far as its large parts are concerned, does not break down, and a supply of the lighter spare parts provides for all emergencies, such as are ordinarily met. On the other hand, it is well to note the many advantages due to the use of different engines. There is, in particular, much to be said in favor of the plan of installing small wing engines in a triple-screw ship. It is a fact that commanders of our ships hesitate, as naturally they should, to enter or leave a port with only one screw in use. They desire to retain the practical advantages of handiness accompanying the use of twin screws. It is, further, a fact that ships which ordinarily cruise at speeds of from 14 to 16 knots, we have found to make better speeds in time of war than ships of the same class but of lower cruising speed. These conditions, combined with the proved efficiency of the use of the wing engines at speeds up to 17 or 18 knots, have been with us the determining factors in causing the adoption of designs involving the use of the smaller wing engines. It has been found advisable to fit economical machinery for cruising at speeds as high as 16 knots. While engines which will be most economical at this speed will not be the most desirable in this respect for a speed of 10 knots, they will retain considerable advantage over any other system in the reserve which will be ready for instant use.

The problem of the design of the propellers to give a proper efficiency for low speeds, and to be good also at the highest speed, offers in this system no difficulties. The reduction in the size of the wing engines, below what would be necessary if three equal engines were used, effects a saving of about 200 H. P., or its equivalent, in steam, due to the decreased condensation on account of the smaller engines. This figure applies exactly to our recently designed 22-knot armored cruisers. The ship is economical at all the ordinary cruising speeds from 10 to 17 knots. The tactical advantages of working with twin screws are retained at all speeds, high or low. It has been pointed out that the decrease in size of screw is especially advantageous for the wing screws, and that it is advantageous, on account of the superior propulsive efficiency of the screw working in the following wake, to have a large power on the center engine. These conditions are especially well fulfilled by the use of the smaller wing engines.

To reduce the engine-room space it is advisable to place engines abreast in the ship. It is also a great advantage to arrange the engines in this way, as it makes possible the placing of a part of the boiler power abaft the engine, which gives easy solution to all problems connected with the change in trim due to the use of light water-tube boilers, and also reduces vibration by placing the engines in the strongest part of the ship. In fact, the center and most powerful engine is exactly at the point of greatest resistance of the hull to vibration. By using smaller wing engines it is also easier to arrange the engines abreast than it would be to install twin-screw engines of the same total power. This follows from the lozenge shape of the space available for the engine rooms beneath the sloping protective deck, and above the rising bottom of the ship. Again, but one screw is dragged with the two engines in use. This screw is a large one, it is true, but the drag is probably not so great as it would be with two smaller screws of the same total power.

It is also regarded as an advantage for this system that there is always one-half the full power available in case of accident. The center engine is seldom used, and our experience goes to show that it is always in a condition of very good efficiency. The customary employment of the smaller wing engines ensures ease of making the regular repairs. It is but fair that I should state, that, with its very large screw, designed for transmitting about half the total power at full speed, the use of the center engine alone may prove slightly more economical than that of the wing screws for a speed of about 10 knots, this superior efficiency following from the working of the screw in the following wake. I do not expect, however, that the center engine will often be alone employed, as the manœuvring qualities and general handiness of the ship are so much improved by the use of two screws at all times. It should, however, be pointed out that the handiness will be retained at full power, and will not be affected badly by the reduction in the size of the wing engines.

In a word, the arrangement of triple-screw engines, with approximately one-half the total power placed upon the center engine, and approximately one-quarter on each of the wing engines, seems to fit a warship and its conditions remarkably well.

Ramming and torpedoing would lose much of their danger with the small engines outboard. There is a certain prejudice among naval officers against any system that shows so plainly as do triple screws, the enormous amount of power installed in the ship and so seldom employed. These officers would possibly prefer to imagine all the power in use, even when knowing, as they all certainly do know, that frequently not 10 per cent of the total power is actually being developed. The loss from drag of an idle screw is plainly seen, but they forget the loss in the engine cylinders from condensation, which is often much greater. Not to employ ordinarily the reserve power plant, increases the value of this reserve as well as the economy. It may appear unwise to install a plant that is so seldom used, yet when the power is wanted it will be wanted badly, and at such times every pound of coal in the bunkers may be worth a ton at ordinary times.

The use of two screws with two engines upon each shaft has not been considered as an alternative to the use of triple screws. This arrangement, with its four engines, has nearly all of the disadvantages attendant upon the use of three screws, with very few of their advantages. Further, it presents the grave tactical disadvantage which was developed so fully in the cases of the Brooklyn and New York at Santiago. These vessels were fitted with four engines working twin screws, the forward engines being ordinarily uncoupled. This system was designed to insure economical running at low speeds; but it was impossible to couple up the forward engines without stopping the ship. During the battle of Santiago, stopping the ship for the fifteen minutes necessary to couple up the engines would have been fatal. On the contrary, in the case of the Minneapolis the center screw was coupled up while the two wing screws were driving the vessel at a speed of 17 knots. This was done when the ships of Admiral Schley were sighted off Santiago, and before the identity of his fleet was established. It is a great advantage that full power can always be applied on a triple-screw ship without stopping. Such conditions would surely have been very valuable to the New York at Santiago.

It may naturally be inquired why the superior efficiency due to the use of triple screws has not led to their general adoption in the merchant marine. Triple screws undoubtedly would have been used in that service if the conditions obtaining were the same as those existing in the navy. Merchant vessels, however, instead of running at a variable speed, are always worked at their full power, and there would be, consequently, no advantage to their owners in fitting machinery capable of working economically at low speeds. The stroke of engines in these vessels is also not limited by a protective deck, and it is always possible with them to obtain the great piston speed necessary for economy by increasing the height of the engine. We see, therefore, that two of the main reasons for the use of triple screws in men-of-war do not obtain in the merchant service. Added to this must be the fact, that the cost of building and installing three engines, when not all of the same size, is considerably greater than that of two engines of the same total power; and also, that the cost of maintenance due to the larger force required would be considerably increased. From these considerations it would appear that triple screws may not be desirable for the merchant service, under present conditions of size and speed. I think, however, that any Transatlantic line which would definitely adopt the triple system, would be patronized by a considerable number of persons, because of the greater security afforded by its use.

The statements I have made as to the desirability of using three screws on war vessels, and the fact that they are being used to so great an extent in the continental navies, will naturally lead the thoughtful student to wonder why they have not been adopted, to some extent at least, in British vessels. This feeling will be the stronger from the fact that British engineers are justly considered to be thoroughly progressive, and abreast of the times with respect to every feature that would tend to an increase in the efficiency of vessels.

It has occurred to me that, whatever other reasons may have caused this non-use, until now, of triple screws on British vessels, one feature of the case at least may serve as a partial explanation. I am led to this belief all the more from the fact that it agrees with the experience of all designers with respect to some forms of marine machinery, which, while apparently very peculiar, are the best adapted to the particular cases where they have to be used, viz., the exceedingly light draft steamers required for certain river service.

Yacht designers are very familiar with the fact that vessels designed for general cruising on the English coast are very different from those for general use on the coast of the United States, due to the fact that in England there is everywhere an ample depth of water, while in the United States the reverse is the case.

In just the same way, we in the United States are restricted in the draft of our war vessels to about 24 feet, while the large British ships can, and do, in some cases, draw about 27 feet. As a consequence of this radical difference in the circumstances under which large powers have to be applied, the problem of the number of propellers is presented to the designers on the two sides under a different aspect, and I am inclined to believe that this has had a great deal to do with the fact that British designers have not paid much attention to three screws thus far. Had they been compelled to face the problem of putting large powers in light-draft hulls, I think they would have been driven to a consideration of the advantages of three screws, and probably would have taken hold of the matter with their characteristic energy.

Let me add, in conclusion, that I have given this subject of triple screws very careful study, and I believe that for war vessels their use is thoroughly logical.

Further than that, I believe that, although contrary to the generally accepted idea of duplication of parts, as far as possible, the plan which I have suggested for dividing the power between one large central engine, to develop about half the power, and two smaller wing engines, each about one-quarter power, will give the best results, and is likely to be the system that will finally obtain general adoption.

THE CASE OF TRIPLE SCREWS.

Their Advantages.

Smaller engine parts.
Greater ease of overhauling.
Greater accuracy of adjustment.

Lack of vibration.
Subdivision of power.
Increased (probable) available power.
Increased ease of protection.
Increased handiness when partly disabled.
Smaller water-tight compartments.
Smaller propellers.
More efficient propellers.
Less peripheral speed of propellers.
Less screw friction.
Increased revolutions of engines.
Decreased loss from cavitation—the word being used in its broadest sense.
Increased efficiency of the screw working in following wake.
Decreased danger to propellers in ramming.
Decreased danger to ship that is rammed or torpedoed.
Shorter propeller shafting.
Decreased racing of screws.
Freer design of stream lines.
Freer access of water to screws.
Increased piston speed and economy.
Decreased total size of cylinders.
Decreased weight of machinery.
Decreased condensation in engines at all—especially at low—powers.
Adaptability to light draft.
High ratio between stroke and diameter of cylinders.
Less glacis plating required.
Ease of propeller design.
Latitude of engine design.
Great gain in economy at low powers.

Their Disadvantages.

Greater number of parts.
Greater number of valves and pipes.
Greater number of auxiliaries.
Increased engine-room force.
Loss of power due to drag of idle screw.
With center engine alone used, the loss of tactical advantages due to twin screws.

THE CASE OF THE PROPOSED SYSTEM OF TRIPLE SCREWS WITH SMALL WING ENGINES.

Advantages.

IT FITS THE SHIP.
Ease of installation and design.
Great gain in economy at all speeds.

The tactical advantages of twin screws economically retained.

Engine-room space is reduced.

The powerful center engine has a most economical screw working in following wake.

The vibration is minimized.

The loss from drag of screw is minimized, one screw only being dragged.

Small size of working parts.

Two independent plants, each capable of economical propulsion up to fifteen knots speed.

Small size of working parts, with maximum ease of repairs.

Disadvantages.

Two sizes of engines in same ship.

Increased cost of building.

Increased number of spare parts necessarily carried.

The disadvantages are few, and, from a broad standpoint of military excellence, they are unimportant. The advantages are many, including better design and installation, greater ease of maintenance, and greater efficiency at all speeds. I consider this the logical arrangement of motive machinery on high-powered warships.

APPENDIX B.

LIST OF TEXT-BOOKS OF STEAM ENGINEERING IN WHICH ELABORATIONS OF THE REPLIES CONTAINED IN THIS BOOK CAN MOST READILY BE FOUND.

The following named books will be found of value to any one who desires to go more thoroughly into the details of the points covered in this paper:

A Manual of Marine Engineering, A. E. Seaton; Seaton and Roundthwaite's Pocket Book of Marine Engineering; Elements of Machine Design, Unwin; The Steam Engine, Rankine; The Marine Steam Engine, Sennett and Oram; Boilers, Marine and Land, Thomas W. Trail; Manual of Naval Architecture, W. H. White; Marine Propellers, S. W. Barnaby; Resistance and Propulsion of Ships, W. F. Durand; Resistance of Ships and Screw Propulsion, D. W. Taylor.

xing

eing

sion

nil-
are
of
his
red

A-

ne
ts

ad
of
a-
l,
;
f
,

UNIVERSITY OF CALIFORNIA LIBRARY
BERKELEY

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

Books not returned on time are subject to a fine of 50c per volume after the third day overdue, increasing to $1.00 per volume after the sixth day. Books not in demand may be renewed if application is made before expiration of loan period.

FEB 6 1918

FEB 20 1918

MAR 4 1922

2Mar'61LF

REC'D LD

MAR 2 1961

23Aug'62TW

REC'D LD

AUG 15 1962

50m-7,'16

YC 67321

360513
Chandler
VM600
C4
UNIVERSITY OF CALIFORNIA LIBRARY